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ELECTRONIC DESIGN OF AN ELECTRONIC HIGH TORQUE-TO-INERTIA SERVO--ETC(U)
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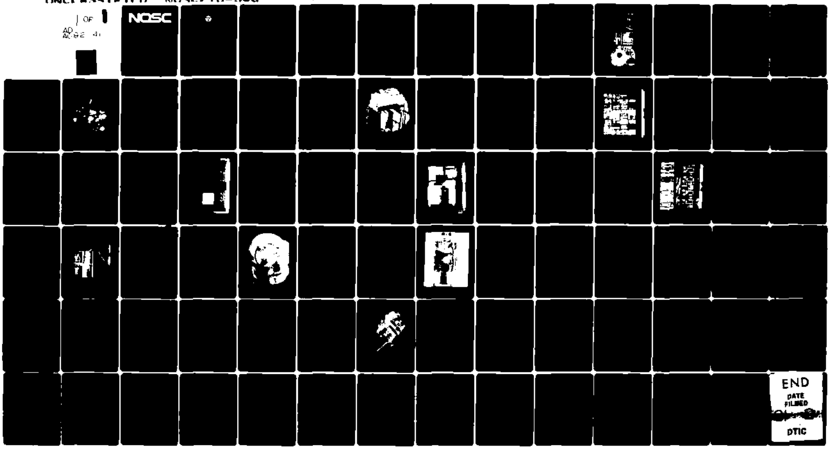

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ELECTRONIC DESIGN OF AN ELECTRONIC HIGH TORQUE-TO-INERTIA SERVOSYSTEM

Candidate system uses include missile guidance, surveillance, and tracking

C.F. Buman

April 1980

Prepared for
Naval Air Systems Command
Electromagnetic Radiating Source Elimination (ERASE),
Code AIR-360H

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92152

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HL BLOOD
Technical Director

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Electronic design and development of a high torque-to-inertia servosystem for stabilizing a sensor system are described. The design philosophy leads to a low-cost/high-performance system. The stabilizing element developed is universal and has application for 1) missile guidance, 2) surveillance, and 3) tracking sensor systems. The servo design is based on math models and is used for electronic design implementation and evaluation.

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TABLES (Continued)

I. INTRODUCTION

This document provides data for the servoelectronics system used to drive an antenna platform for missile guidance applications. The servoelectronics system is illustrated in figure 1. A complete analysis of the system is provided in reference 1. It would benefit the reader to use that reference in conjunction with this document. The servoelectronics analysis was arrived at by using the given antenna platform mechanical and electrical characteristics (such as torque motor electrical characteristics, mechanical gearings, and expected inertia load conditions). The purpose of this document is to present the electrical and electronic design data required to complete the hardware for the servoelectronics loop. In addition, a limited set of mechanical drawings is included to complete the documentation.

The system is capable of driving two separate platforms: the 10-inch torque motor-driven antenna platform, which is the platform discussed in this document; and a 5-inch magnetic particle clutch motor-driven antenna platform designed by Hughes Aircraft Company. The necessary card change (servoamplifier card and current drivers) and component changes on the compensation card are pointed out in the appropriate sections.

The electronics was designed for laboratory use only, and certain shortcuts were taken (such as minimal packaging) in the design process to control cost and to meet a short schedule. Another design iteration is required to provide units suitable for flight test. Cost, weight, and size reduction will be addressed in a redesign.

II. ELECTRICAL DESIGN

The electrical design section provides the electrical interfaces and interconnections. The electrical design permits ready access to critical areas for testing and modification purposes and is easily set up to provide a good portable laboratory test bench. Interfaces with supporting equipment and system components are easily accomplished. Figure 2 illustrates system interfaces and connections.

A. WIRING HARNESS

The wiring harness diagram, as shown in figure 3, illustrates the interconnections between the control panel and the card cage and between the card cage and the antenna platform. It also illustrates signals coming from the video processor (not discussed in this document) and necessary power-supply connections. The cable between the control panel and the card cage was made 15 feet long so as to allow adequate separation between the operator and the antenna platform for rf interference suppression and testing purposes. The cable between the card cage and the platform is 2 feet long. Table 1 contains the parts list for the wiring harness.

B. CONTROL PANEL

The main function of the control panel, shown in figure 4, is to allow manual operation and monitoring of the servoelectronics system. The control panel schematic is illustrated in figure 5. Test jacks are provided to permit monitoring of pertinent signals. The flight programmer control panel switch is provided to transfer control from the control panel to the flight programmer (video processor signals).

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[1]NOSC TR 527, High Torque-to-Inertia Servo System for Stabilizing Sensor Systems, by F. D. Groutage, 1980.

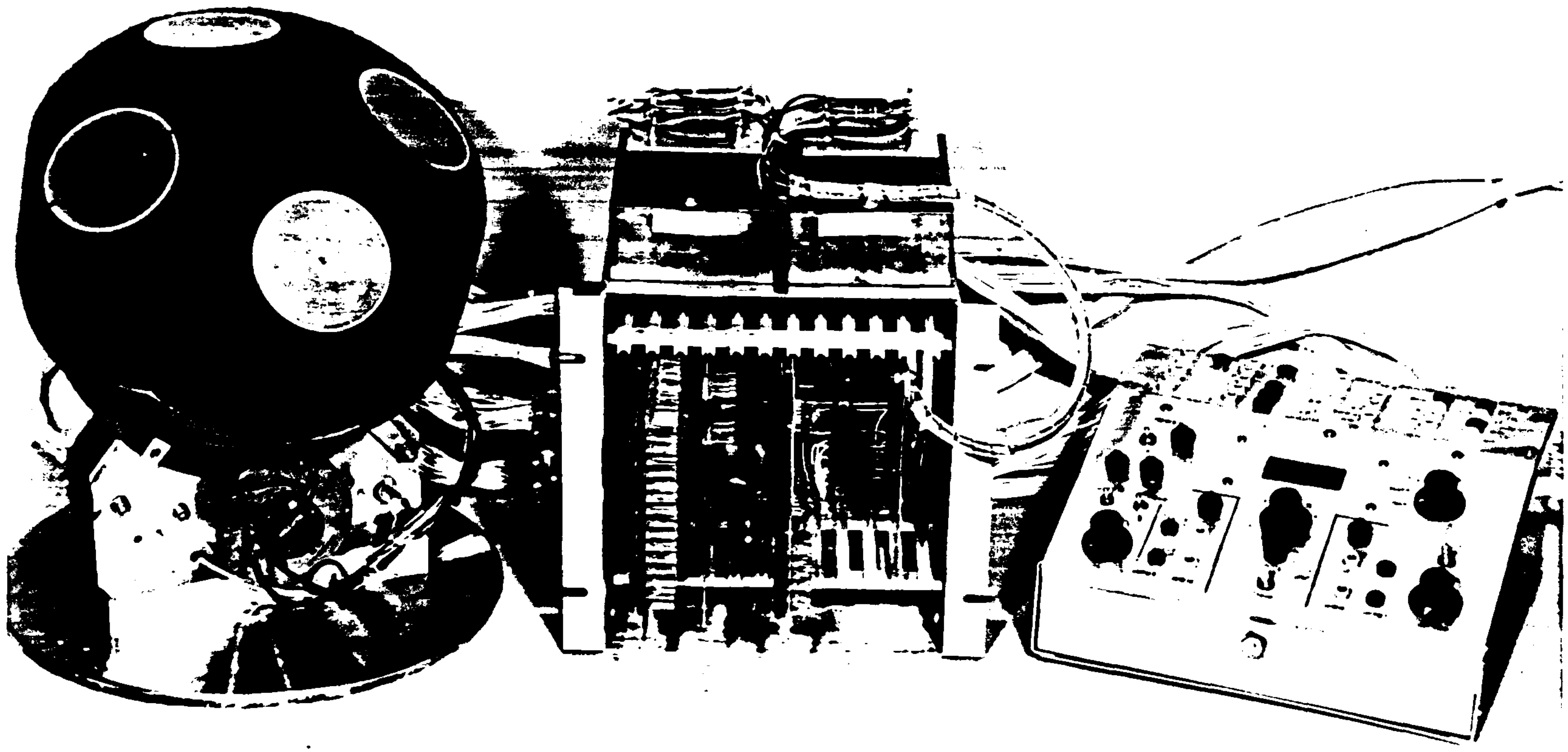


Figure 1. Servoelectronics system.

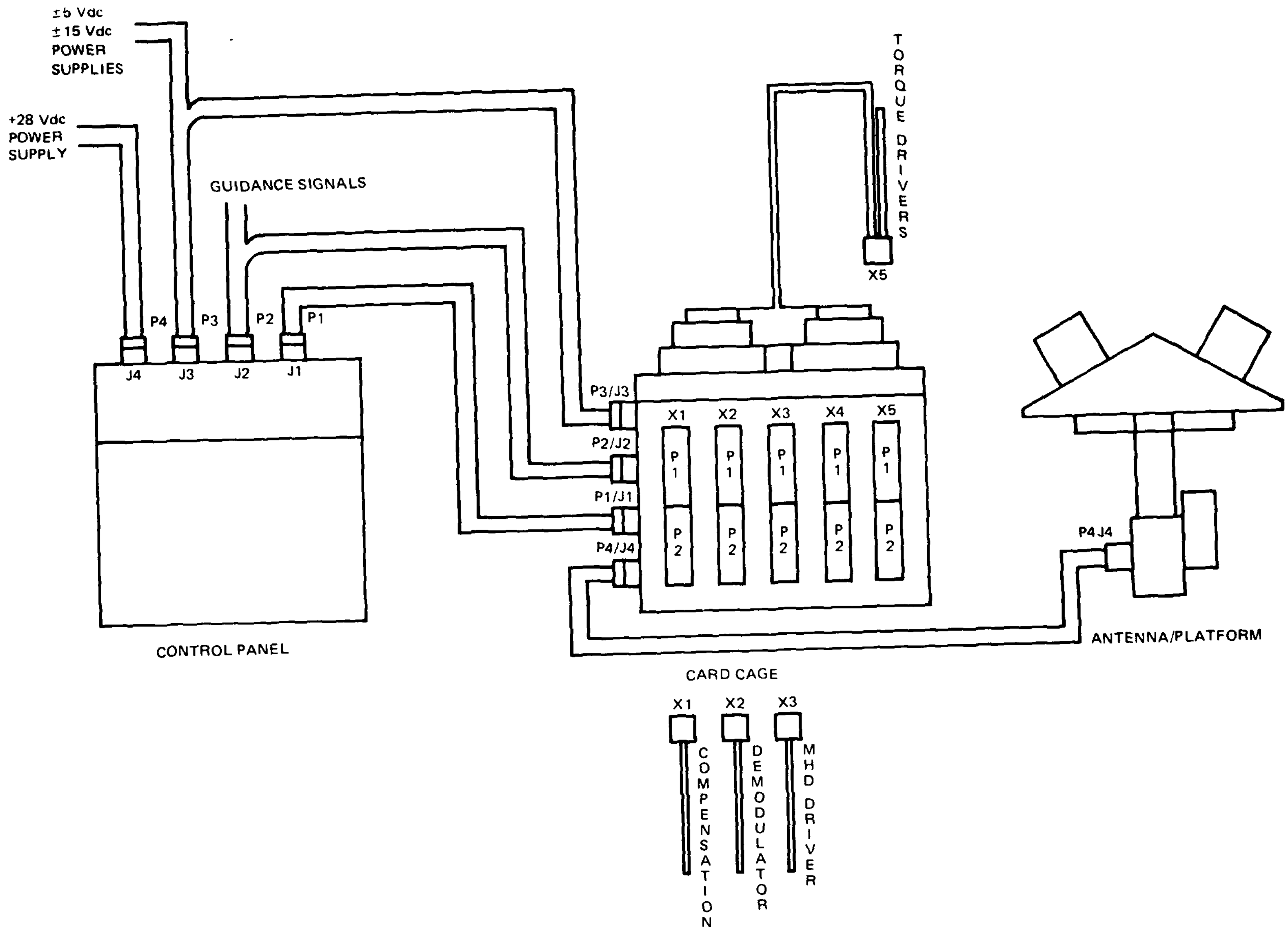
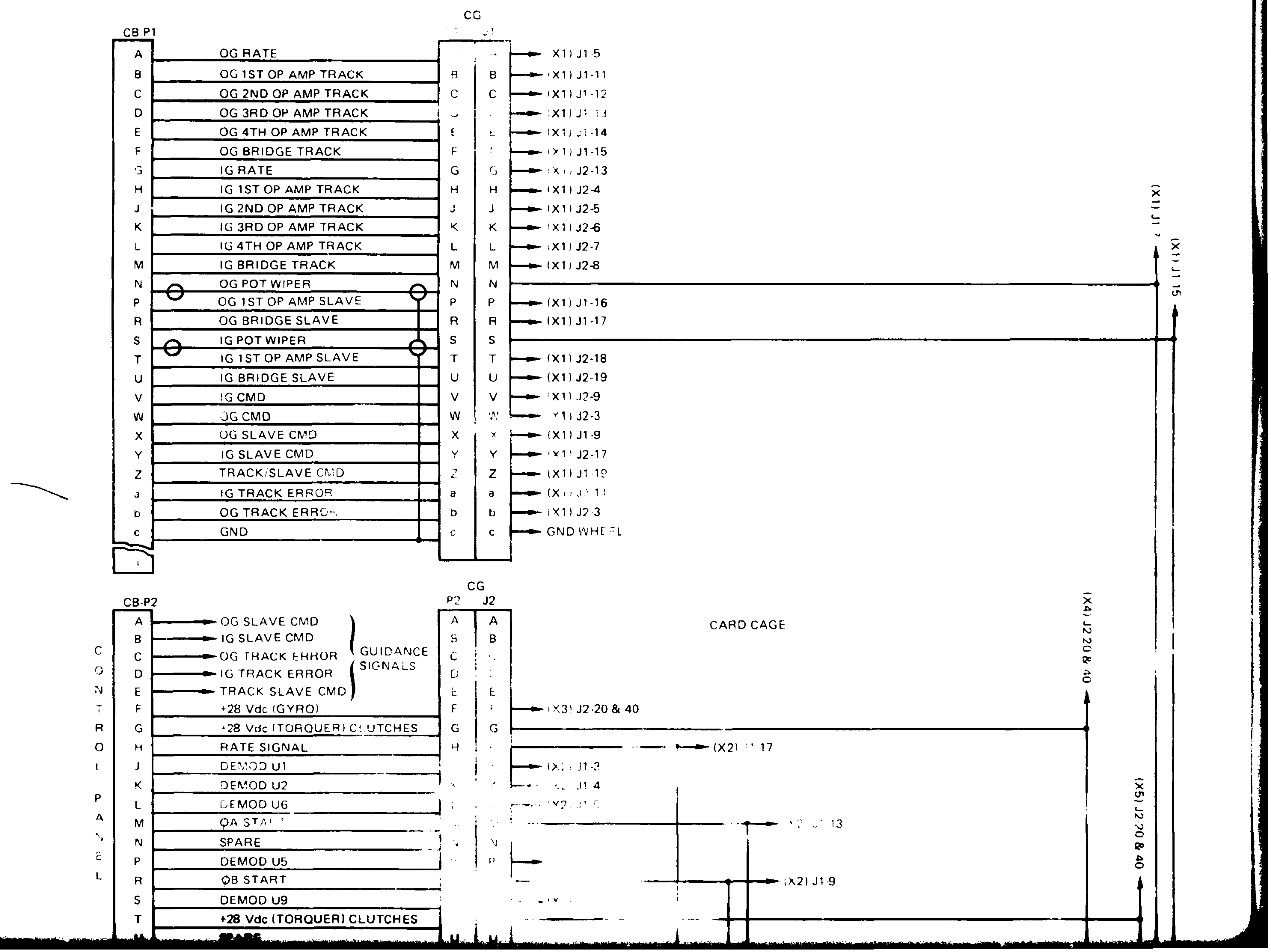


Figure 2. System block diagram.



CB P1
CG
J1
A OG RATE
B OG 1ST OP AMP TRACK
C OG 2ND OP AMP TRACK
D OG 3RD OP AMP TRACK
E OG 4TH OP AMP TRACK
F OG BRIDGE TRACK
G IG RATE
H IG 1ST OP AMP TRACK
J IG 2ND OP AMP TRACK
K IG 3RD OP AMP TRACK
L IG 4TH OP AMP TRACK
M IG BRIDGE TRACK
N OG POT WIPER
P OG 1ST OP AMP SLAVE
R OG BRIDGE SLAVE
S IG POT WIPER
T IG 1ST OP AMP SLAVE
U IG BRIDGE SLAVE
V IG CMD
W OG CMD
X OG SLAVE CMD
Y IG SLAVE CMD
Z TRACK/SLAVE CMD
a IG TRACK ERROR
b OG TRACK ERROR
c GND
X1) J1-5
(X1) J1-11
(X1) J1-12
(X1) J1-14
(X1) J1-15
(X1) J2-13
(X1) J2-4
(X1) J2-5
(X1) J2-6
(X1) J2-7
(X1) J2-8
(X1) J1-16
(X1) J1-17
(X1) J2-18
(X1) J2-19
(X1) J2-9
(X1) J2-3
(X1) J1-9
(X1) J2-17
(X1) J1-19
(X1) J2-3
GND WHEEL
(X1) J1-7
(X1) J1 15
CB-P2
CG
P2 J2
A OG SLAVE CMD
B IG SLAVE CMD
C OG TRACK ERROR
D IG TRACK ERROR
E TRACK SLAVE CMD
GUIDANCE SIGNALS
F +28 Vdc (GYRO)
G +28 Vdc (TORQUER) CLUTCHES
H RATE SIGNAL
J DEMOD U1
K DEMOD U2
L DEMOD U6
M ØA START
N SPARE
P DEMOD U5
R ØB START
S DEMOD U9
T +28 Vdc (TORQUER) CLUTCHES
CONTROL PANEL
CARD CAGE
(X3) J2-20 & 40
(X2) J1 17
(X2) J1-9
(X4) J2 20 & 40
(X5) J2 20 & 40

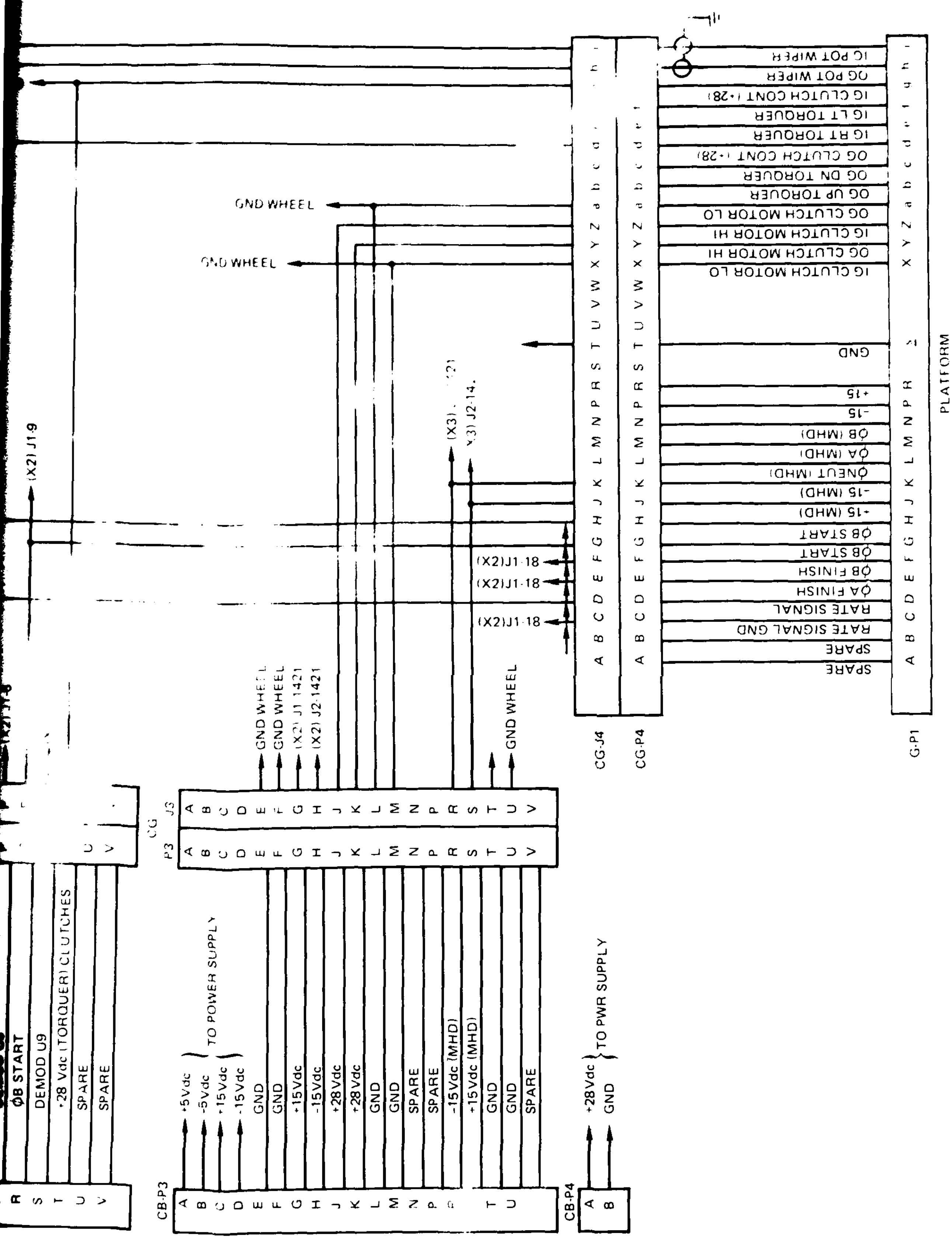


Figure 3. Wiring harness interconnections.

Item	Quantity	Part Number	Manufacturer	Nomenclature
CB-P1	1	PT06A-18-32P (SR)	Bendix	Connector
CB-P2	1	MS3116E14-19SW	Bendix	Connector
CB-P3	1	PT06E-14-18SW (SR)	Bendix	Connector
CB-P4	1	MS3106R16-11S (C)	Cannon	Connector
CG-P1	1	PT06A-16-26S (SR)	Bendix	Connector
CG-P2	1	MS3116E14-19SW	Bendix	Connector
CG-P3	1	PT06E-14-18SW (SR)	Bendix	Connector
CG-P4	1	PT06A-18-32S (SR)	Bendix	Connector
G-P1	1	PT06SE-20-39PY	Bendix	Connector

Table 1. Wiring harness parts list.

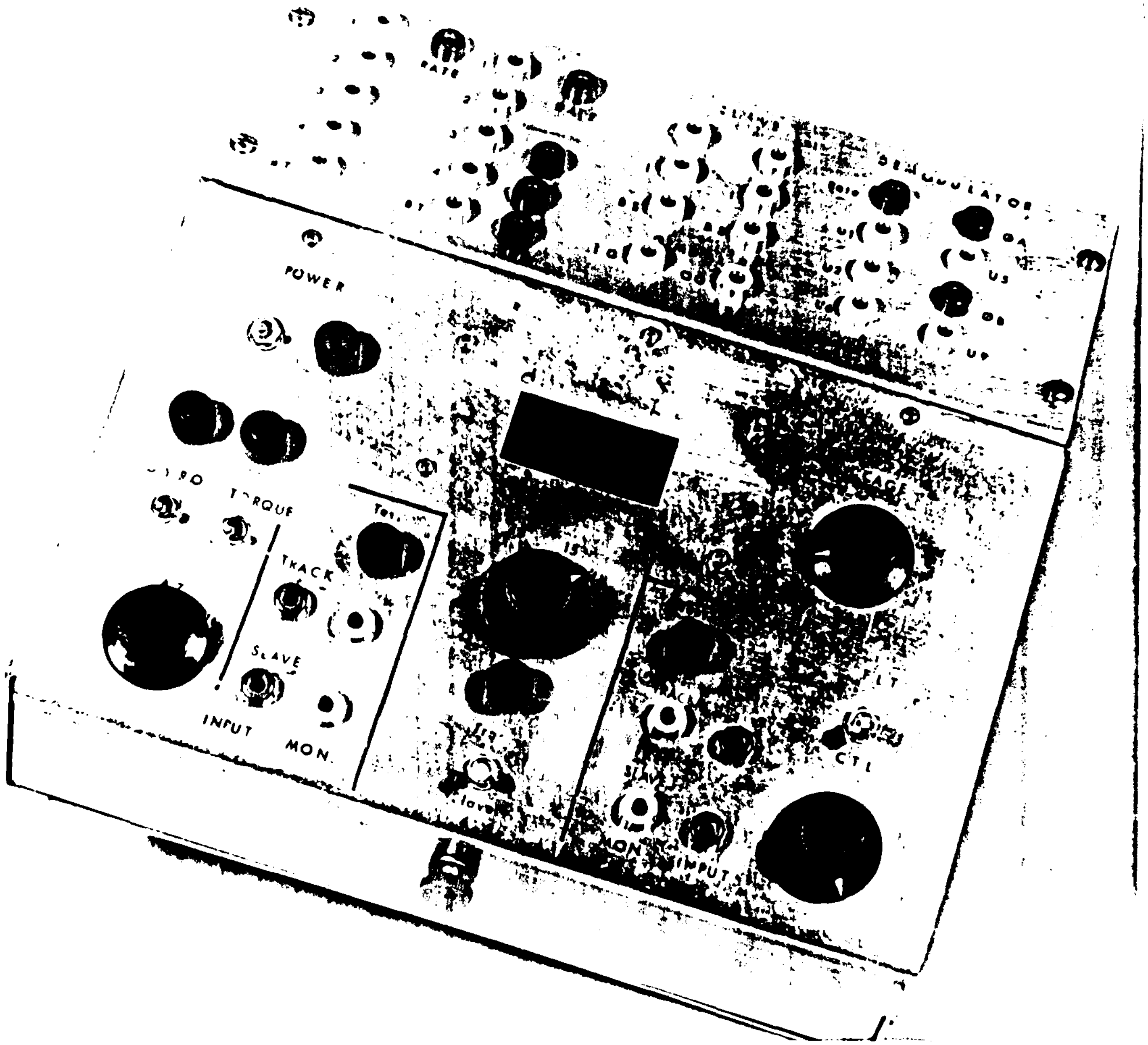
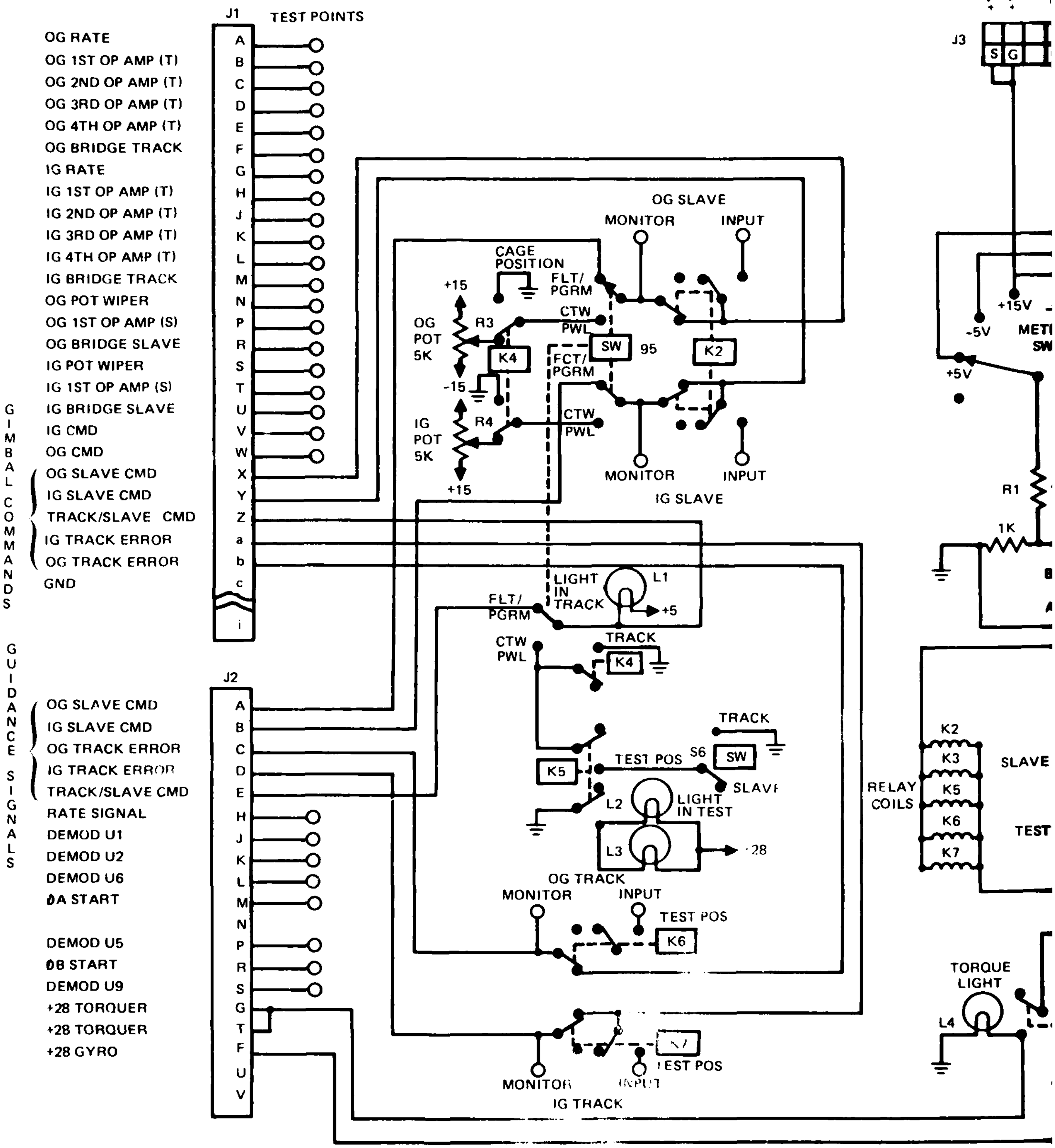


Figure 4. Control panel.


J1
TEST POINTS
OG RATE
OG 1ST OP AMP (T)
OG 2ND OP AMP (T)
OG 3RD OP AMP (T)
OG 4TH OP AMP (T)
OG BRIDGE TRACK
IG RATE
IG 1ST OP AMP (T)
IG 2ND OP AMP (T)
IG 3RD OP AMP (T)
IG 4TH OP AMP (T)
IG BRIDGE TRACK
OG POT WIPER
OG 1ST OP AMP (S)
OG BRIDGE SLAVE
IG POT WIPER
IG 1ST OP AMP (S)
IG BRIDGE SLAVE
IG CMD
OG CMD
GIMBAL COMMANDS
OG SLAVE CMD
IG SLAVE CMD
TRACK/SLAVE CMD
IG TRACK ERROR
OG TRACK ERROR
GND
J2
GUIDANCE SIGNALS
OG SLAVE CMD
IG SLAVE CMD
OG TRACK ERROR
IG TRACK ERROR
TRACK/SLAVE CMD
RATE SIGNAL
DEMOD U1
DEMOD U2
DEMOD U6
ØA START
DEMOD U5
ØB START
DEMOD U9
+28 TORQUER
+28 TORQUER
+28 GYRO
OG SLAVE
MONITOR
INPUT
CAGE POSITION
FLT/PGRM
CTW PWL
SW
95
K2
K4
FCT/PGRM
OG POT 5K
R3
+15
-15
IG POT 5K
R4
MONITOR
INPUT
IG SLAVE
LIGHT IN TRACK
L1
+5
TRACK
K5
TEST POS
S6
SLAVE
L2
LIGHT IN TEST
L3
+28
OG TRACK
K6
IG TRACK
J3
+15V
-5V
+5V
R1
1K
RELAY COILS
K3
K7
TEST
TORQUE LIGHT
L4

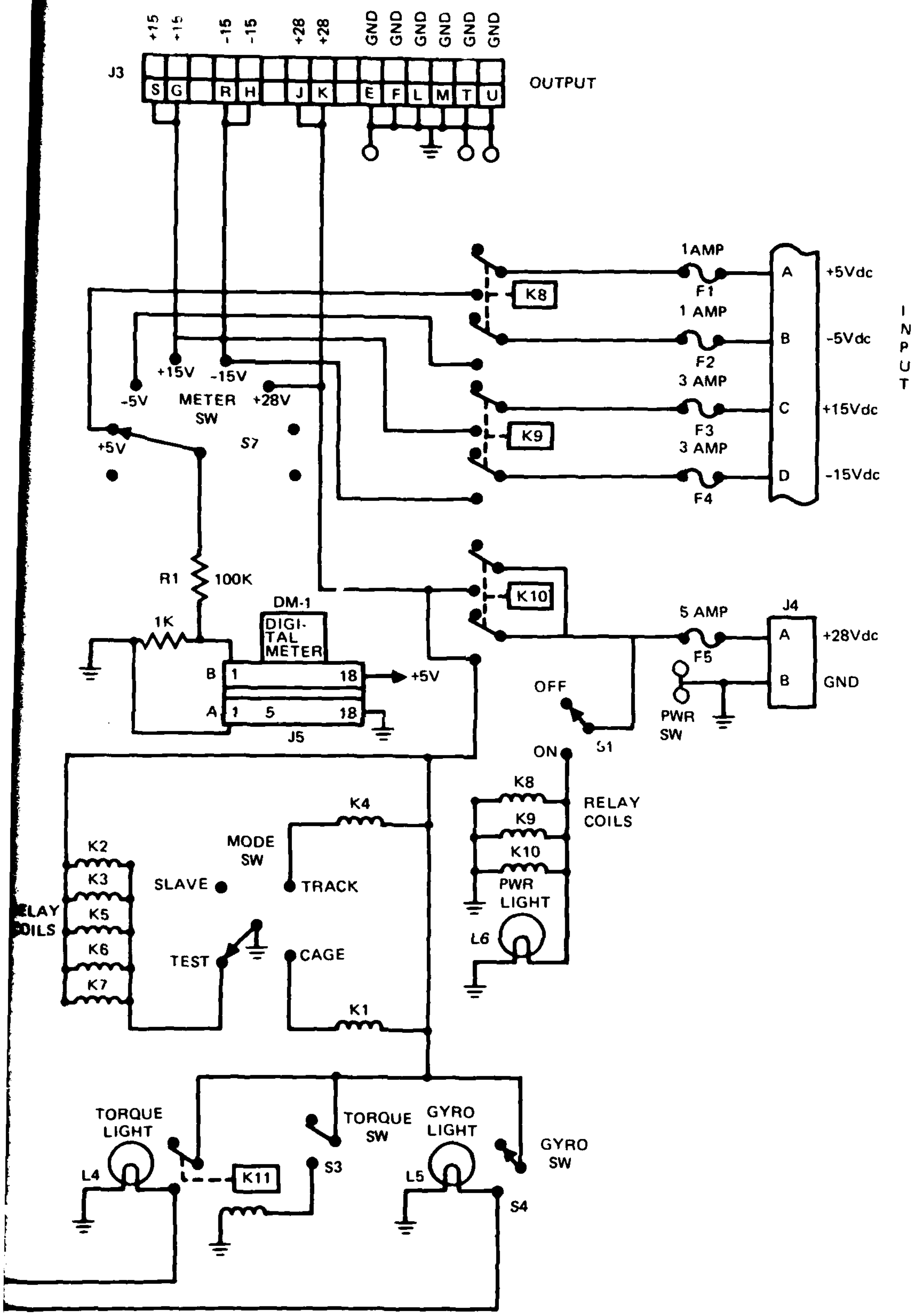


Figure 5. Control panel schematic.

The control panel has several modes of operation. In the TEST mode, signals can be injected to drive the inner and outer gimbal. Two lights are provided to indicate that the input jacks for signal injection are activated for the inner and outer gimbals. When the TRACK/SLAVE switch is in the SLAVE position, the TEST mode permits the injection of an inner and/or outer gimbal slave command to slow the antenna platform. If the TRACK/SLAVE switch is in the TRACK position, the TEST mode permits the injection of an inner and outer gimbal rate signal to control the pointing of the antenna platform. When the system is in TRACK, the TRACK/SLAVE light is activated.

In SLAVE mode, only slave commands can be given and the position potentiometers provide the voltage to slew and position the inner and outer gimbal.

In the TRACK mode, rate signals are provided by the guidance system inputs only. When in either TRACK or SLAVE mode, the TRACK/SLAVE switch is overridden.

In the CAGE mode, the inner and outer gimbals are positioned to look forward or in a zero position.

The digital voltmeter will check the following voltages: +5 Vdc, ±15 Vdc, and 28 Vdc. No power is applied to the servoelectronics until the power switch is on, which is indicated by a light. The torquer and gyro switches apply 28 Vdc to the current drivers and the MHD driver, respectively, as indicated by their respective lights. The control panel parts list is shown in table 2.

C. CARD CAGE

Figure 6 shows the card cage fully assembled. The card cage is the housing and interface wiring for the compensation card, demodulator card, MHD driver card, and the inner and outer gimbal current drivers. The card cage is wired to operate the 10-inch antenna platform (torque motor platform) as well as the Hughes Aircraft Company 5-inch antenna platform (magnetic particle clutch motor platform). The cards are wire-wrapped to permit quick and easy assembly, modification, and addition of test points to the control panel. An extender card was fabricated to enable on-line testing. Table 3 shows the card-cage parts list and figure 7 is the card-cage wiring diagram. A bus system was incorporated with a central ground wheel to eliminate signal and grounding problems.

The card cage and its associated electronics can be significantly reduced in size and weight in a redesign to package for missile applications.

1. Compensation Card

Figure 8 shows the compensation card, which provides the necessary compensation required for the slave and track loops of the servo loop that will be discussed in the electronics design section. The compensation card is inserted into the first slot provided (nearest to connectors) in the card cage (X1). Figure 9 is the compensation card schematic and table 4 is the parts list. The compensation card interconnect diagram is shown in figure 10. The compensation card is made entirely from dual in-line integrated circuits and discrete components.

This is the only card that requires component changes to drive the 5-inch magnetic particle clutch/motor-driven antenna platform. Table 5 shows the necessary component changes.

The switches in figure 9 (U4 and U10) are drawn to represent TRACK mode. If a high input is placed on the TRACK/SLAVE input (P1-19), this activates the switches, places the card in the SLAVE mode, and discharges the capacitors of the integrators (U3 and U9).

Item	Quantity	Part Number	Manufacturer	Nomenclature
DM-1	1	DM1000-4B1A	Date 1	Digital voltmeter
CB-1, CB-2	2	MS3320-1		Circuit breaker (1A)
CB-3, CB-4	2	MS26574-3		Circuit breaker (3A)
CB-5	1	S3320-5		Circuit breaker (5A)
K1-K11	11	J-D4A-008	Leach	Relay
L1	1	507-4758	Dialco	Lamp (6V)
L2-L6	5	#39	Dialco	Lamp (28V)
J1	1	PTO2A-18-32S (SR)	Bendix	Connector
J2	1	MS3112E14-19W	Bendix	Connector
J3	1	PTO2E-14-18PW	Bendix	Connector
J4	1	MS3102A16-11P	Cannon	Connector
J5	1	3VN381JN5	Viking	PC edge connector
R1	1	1/4W 100K		Resistor
R2	1	1/4W 1K		Resistor
R3, R4	2	3543S-1-502	Bourns	Potentiometer (5K)
S1, S3, S4, S5	4	JMT-123	J-B-T	Switch
S2, S7	2	6439	Grayhill	Switch
S5	1	MTL3060	ALCO	Switch
Test points	41			Banana jacks
XL1-XL6	6	508-7545-504	Dialco	Lamp holder
	4			Knobs
	1	See figure 29	NOSC	Frame

Table 2. Control panel parts list.

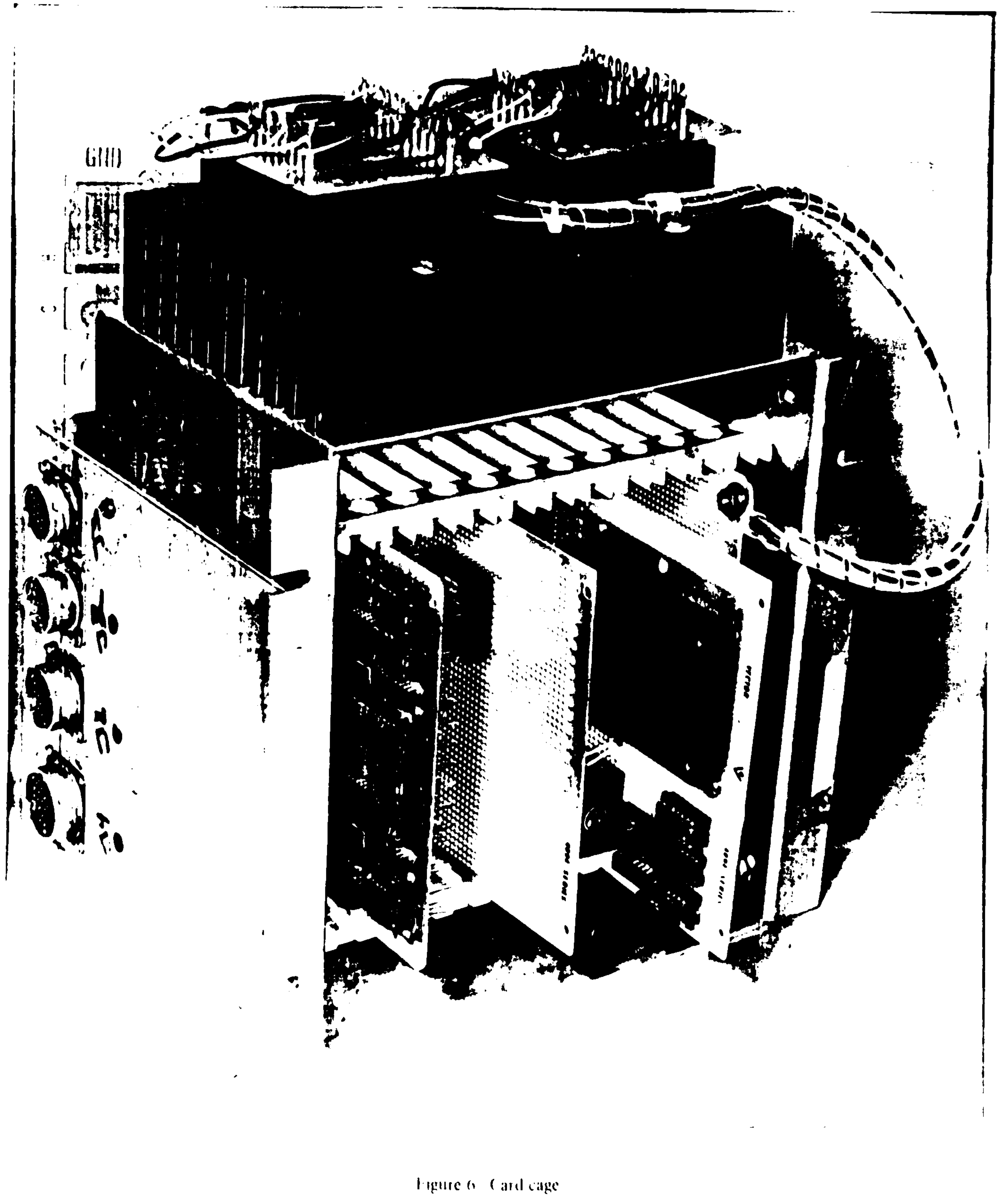
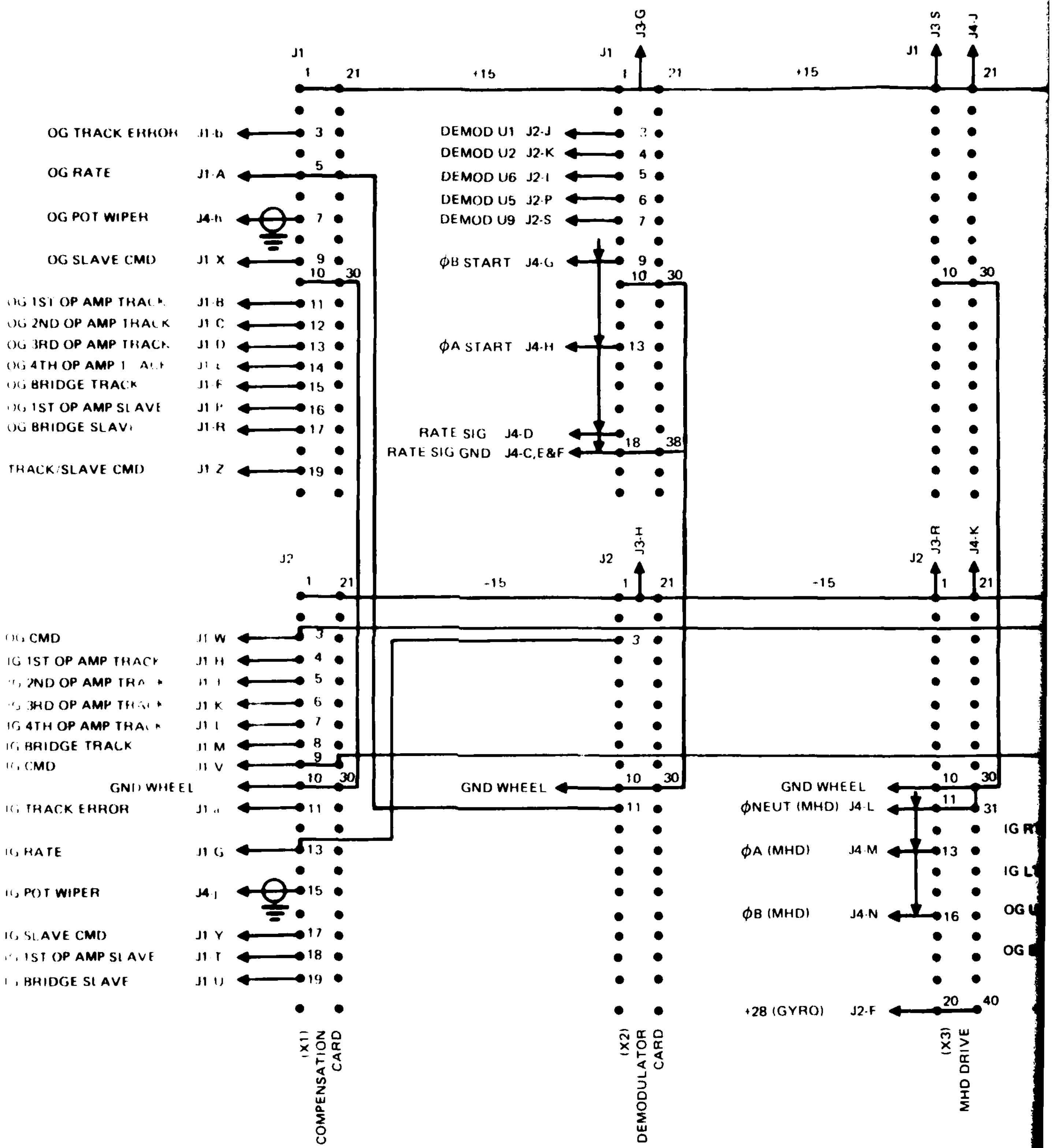


Figure 6. Card cage

Item	Quantity	Part Number	Manufacturer	Nomenclature
CG-J1	1	PTO2A-16-26S (SR)	Bendix	Connector
CG-J2	1	MS3112E14-19SW	Bendix	Connector
CG-J3	1	PTO2E-14-18SW (SR)	Bendix	Connector
CG-J4	1	PT02A-18-32S (SR)	Bendix	Connector
X1-X5	5	0005261	NOSC	Connector
	1	SOCN0004009-2	NOSC	Card cage

Table 3. Card cage parts list.



J1
+15
J3-G
J3-S
J4-J
OG TRACK ERROR J1-b
OG RATE J1-A
OG POT WIPER J4-h
OG SLAVE CMD J1-X
OG 1ST OP AMP TRACK J1-B
OG 2ND OP AMP TRACK J1-C
OG 3RD OP AMP TRACK J1-D
OG BRIDGE TRACK J1-F
OG 1ST OP AMP SLAVE J1-P
OG BRIDGE SLAVE J1-R
TRACK/SLAVE CMD J1-Z
DEMOD U1 J2-J
DEMOD U2 J2-K
DEMOD U6 J2-I
DEMOD U5 J2-P
DEMOD U9 J2-S
ϕB START J4-G
ϕA START J4-H
RATE SIG J4-D
RATE SIG GND J4-C,E&F
J2
-15
J3-H
J3-R
J4-K
OG CMD J1-W
IG 1ST OP AMP TRACK J1-H
IG 4TH OP AMP TRACK J1-L
IG BRIDGE TRACK J1-M
IG CMD J1-V
GND WHEEL
IG TRACK ERROR
IG RATE J1-G
IG POT WIPER J4-j
IG SLAVE CMD J1-Y
IG 1ST OP AMP SLAVE J1-T
IG BRIDGE SLAVE J1-U
ϕNEUT (MHD) J4-L
ϕA (MHD) J4-M
ϕB (MHD) J4-N
+28 (GYRO) J2-F
(X1) COMPENSATION CARD
(X2) DEMODULATOR CARD
(X3) MHD DRIVE

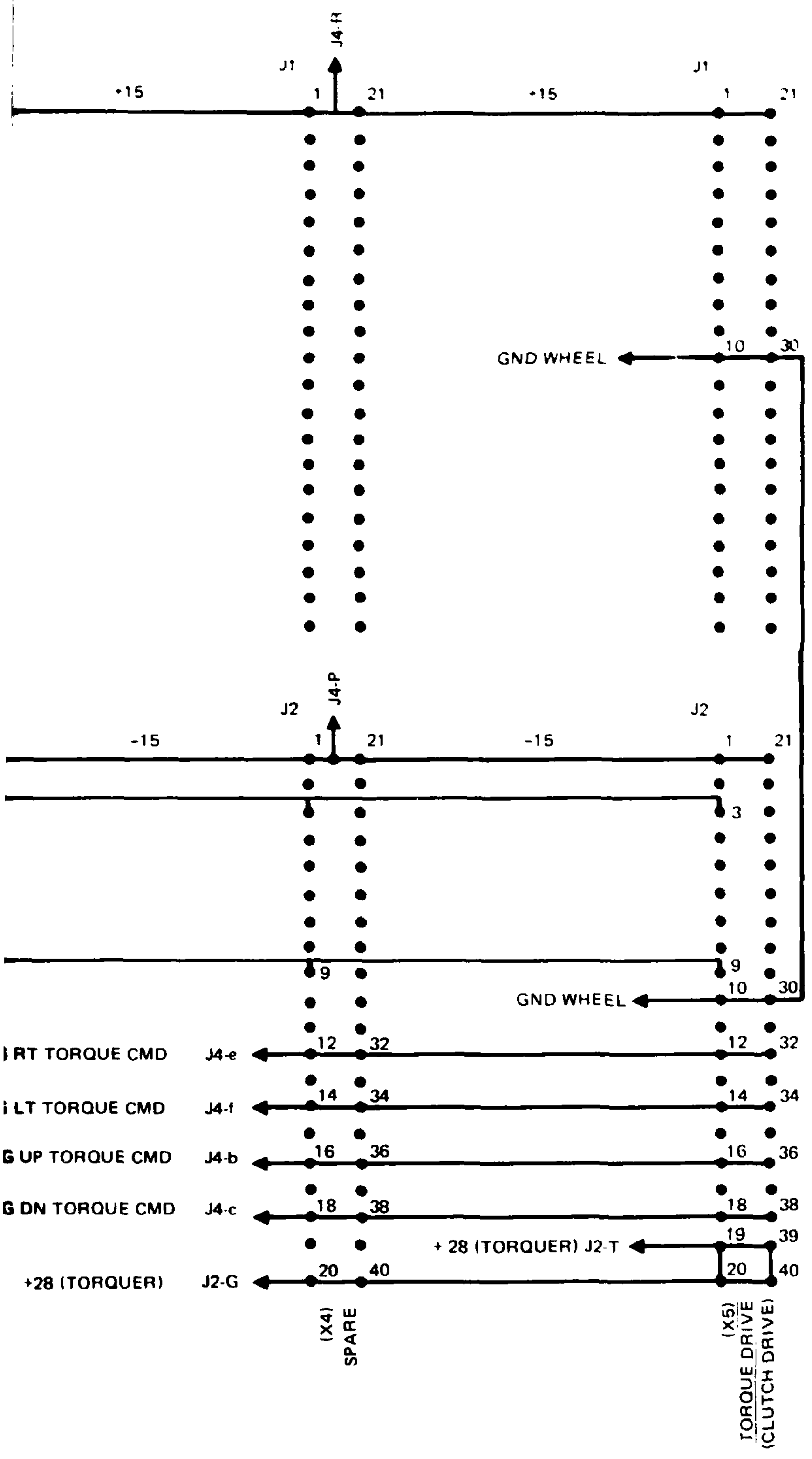


Figure 7. Card case wiring diagram.

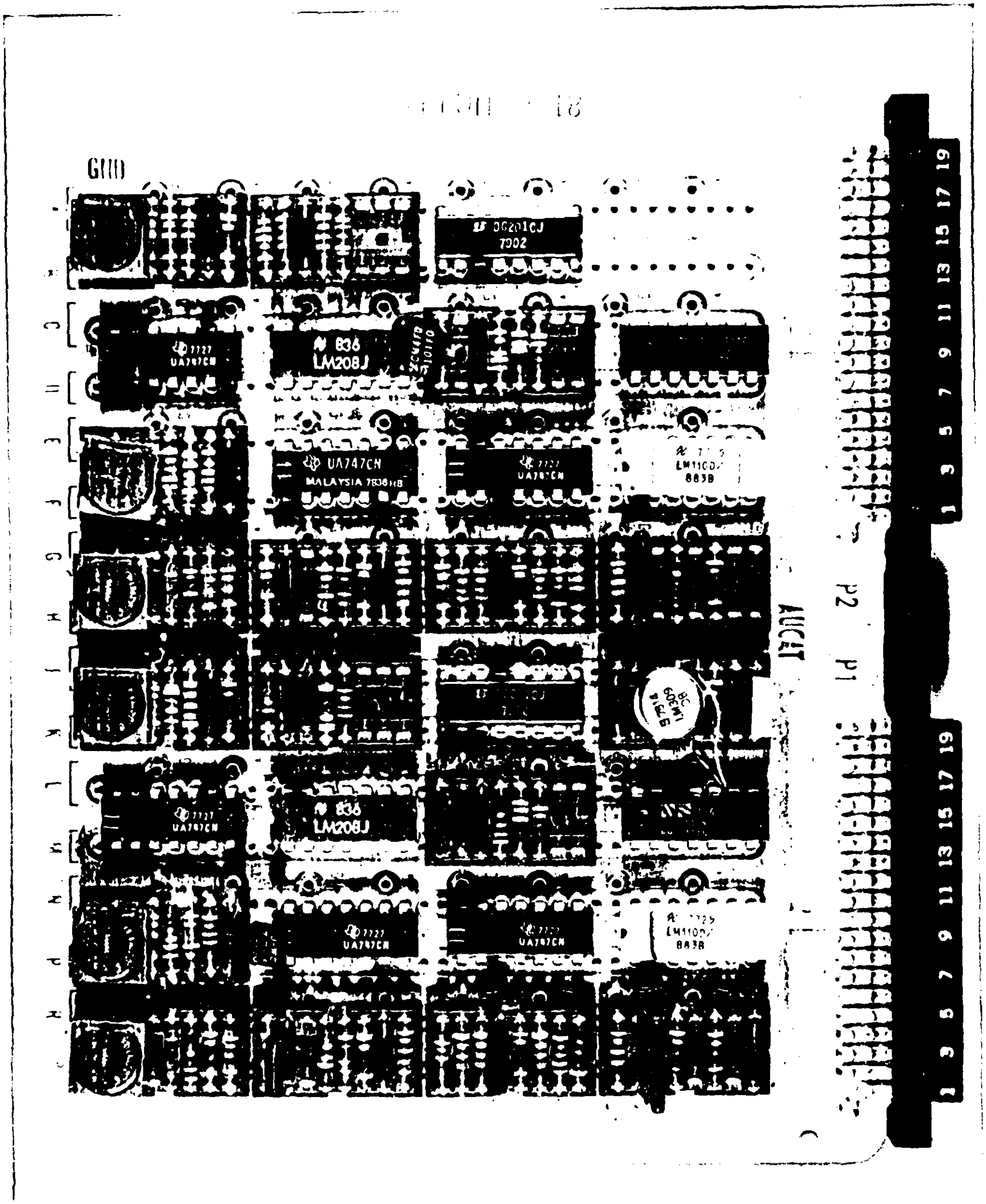
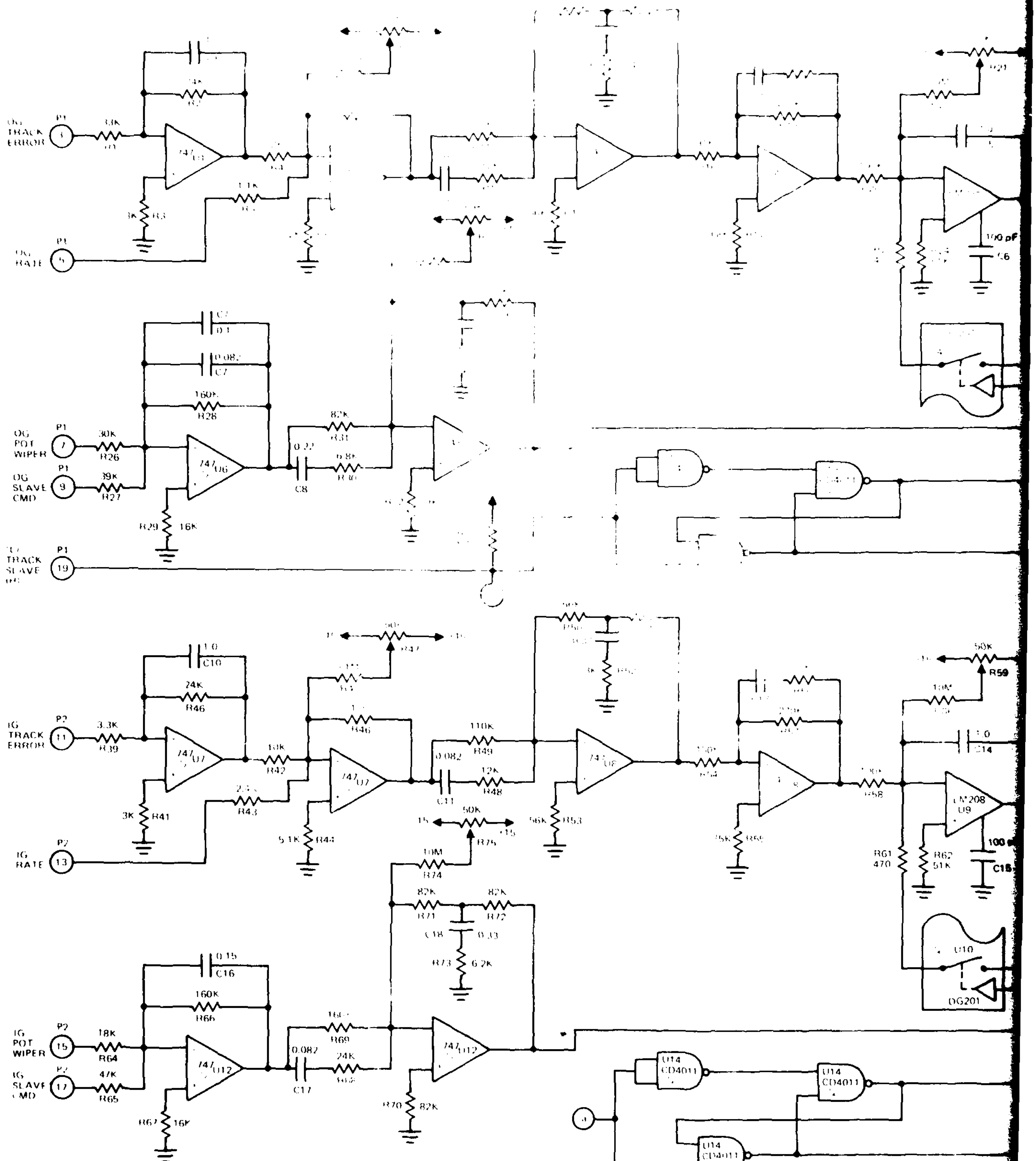


Figure 8. Compensation card.

Item	Quantity	Part Number, Value		Manufacturer	Nomenclature
C1, C5, C9, C10, C14	5	CK06	1 μF		Capacitor
C2, C7, C11, C17	4	CK05	0.082 μF		Capacitor
C3, C12, C18	3	CK06	0.33 μF		Capacitor
C4, C13	2	Red Cap	3.3 μF	ERIE	Capacitor
C6, C15	2	CK05	100 pF		Capacitor
C7	1	CK06	0.1 μF		Capacitor
C8, C19	2	CK06	0.22 μF		Capacitor
C16	1	CK06	0.15 μF		Capacitor
C20, C21, C22	3	CK05	0.01 μF		Capacitor
R1, R39	2	RC07	3.3K		Resistor
R2, R40, R68	3	RC07	24K		Resistor
R3, R4, R14, R41, R52	5	RC07	3K		Resistor
R5	1	RC07	1.1K		Resistor
R6	1	RC07	2K		Resistor
R7	1	RC07	2.2M		Resistor
R8, R15, R42, R46, R63	5	RC07	10K		Resistor
R9, R21, R37, R47, R59, R75	6	3280P	50K	Bourns	Potentiometer
R10, R48	2	RC07	12K		Resistor
R11, R49	2	RC07	110K		Resistor
R12, R13, R15, R50, R51	6	RC07	56K		Resistor
R16	1	RC07	91K		Resistor
R17	1	RC07	68K		Resistor
R18, R26, R56	3	RC07	30K		Resistor
R19, R57	2	RC07	270K		Resistor
R20, R58	2	RC07	100K		Resistor
R22, R36, R60, R74	4	RC07	10M		Resistor
R23, R61	2	RC07	470		Resistor
R24, R62	2	RC07	51K		Resistor
R27, R32, R33, R34	4	RC07	39K		Resistor
R28, R66, R69	3	RC07	160K		Resistor
R29, R67	2	RC07	16K		Resistor
R30	1	RC07	6.8K		Resistor
R31, R70, R71, R72	4	RC07	82K		Resistor
R35	1	RC07	1.5K		Resistor
R38, R44	2	RC07	5.1K		Resistor
R43	1	RC07	2.4K		Resistor
R45	1	RC07	5.1M		Resistor
R54	1	RC07	150K		Resistor
R55	1	RC07	75K		Resistor
R64	1	RC07	18K		Resistor
R65	1	RC07	47K		Resistor
R73	1	RC07	6.2K		Resistor
U1, U2, U6, U7, U8, U12	6	SN74747		Texas Instruments	Integrated circuit
U3, U9	2	LM208J		National	Integrated circuit
U4, U10	2	DG201CJ		Signetics	Integrated circuit
U5, U11	2	LM110D		National	Integrated circuit
U13, U14	2	CD4011		RCA	Integrated circuit
U15	1	LM309DB		National	Voltage regulator
	1	8136-UG115		Augat	Wire wrap board

Table 4. Compensation card parts list.



OG TRACK ERROR
OG RATE
OG POT WIPER
OG SLAVE CMD
TRACK SLAVE
IG TRACK ERROR
IG RATE
IG POT WIPER
IG SLAVE CMD
P1
P2
747 U6
747 U7
747 U12
LM208 U9
U10
DG201
U14 CD4011
100 pF
C7 0.1
0.082 C7
160K R28
30K R26
39K R27
R29 16K
82K R31
0.22 C8
6.8K R30
1.0 C10
24K R46
3.3K R39
3K R41
10K R42
R43
5.1K R44
50K R47
0.082 C11
110K R49
12K R48
56K R53
R54
R58
10M
50K R59
1.0 C14
R61 470
R62 51K
C15
50K R75
10M R74
82K R71
82K R72
C18 0.33
R73 6.2K
0.15 C16
160K R66
18K R64
47K R65
R67 16K
R69
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24K
R70 82K

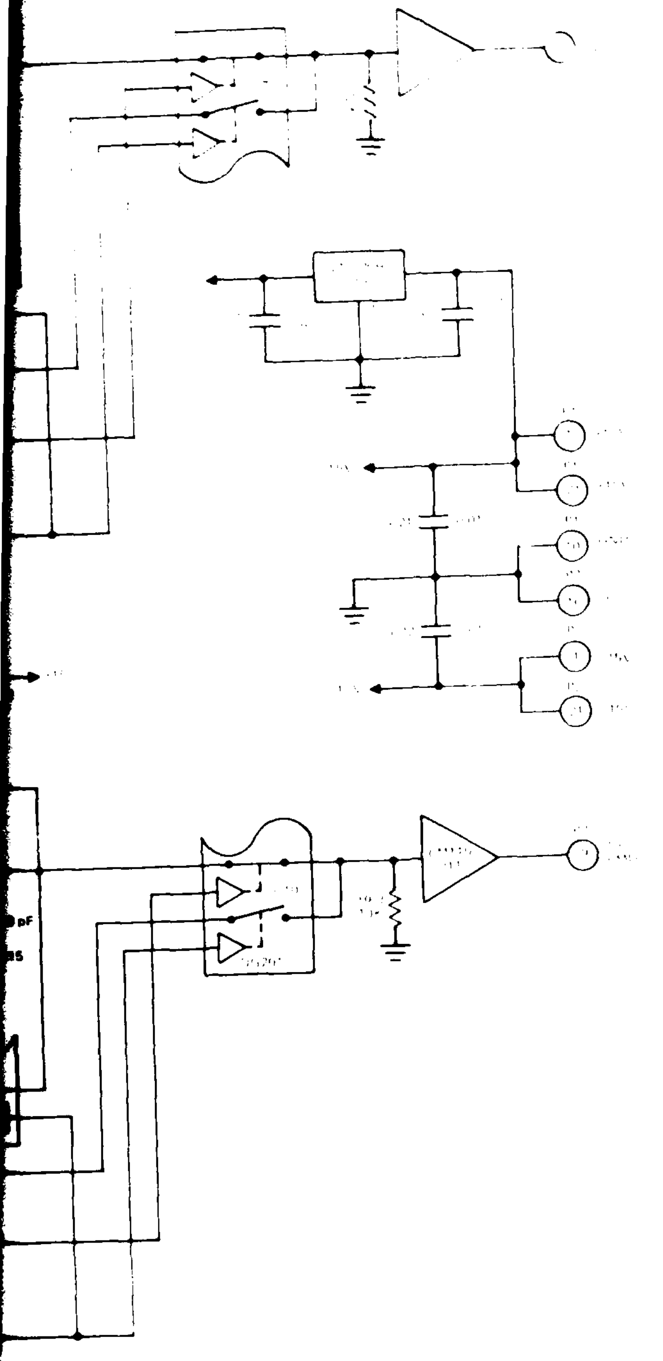
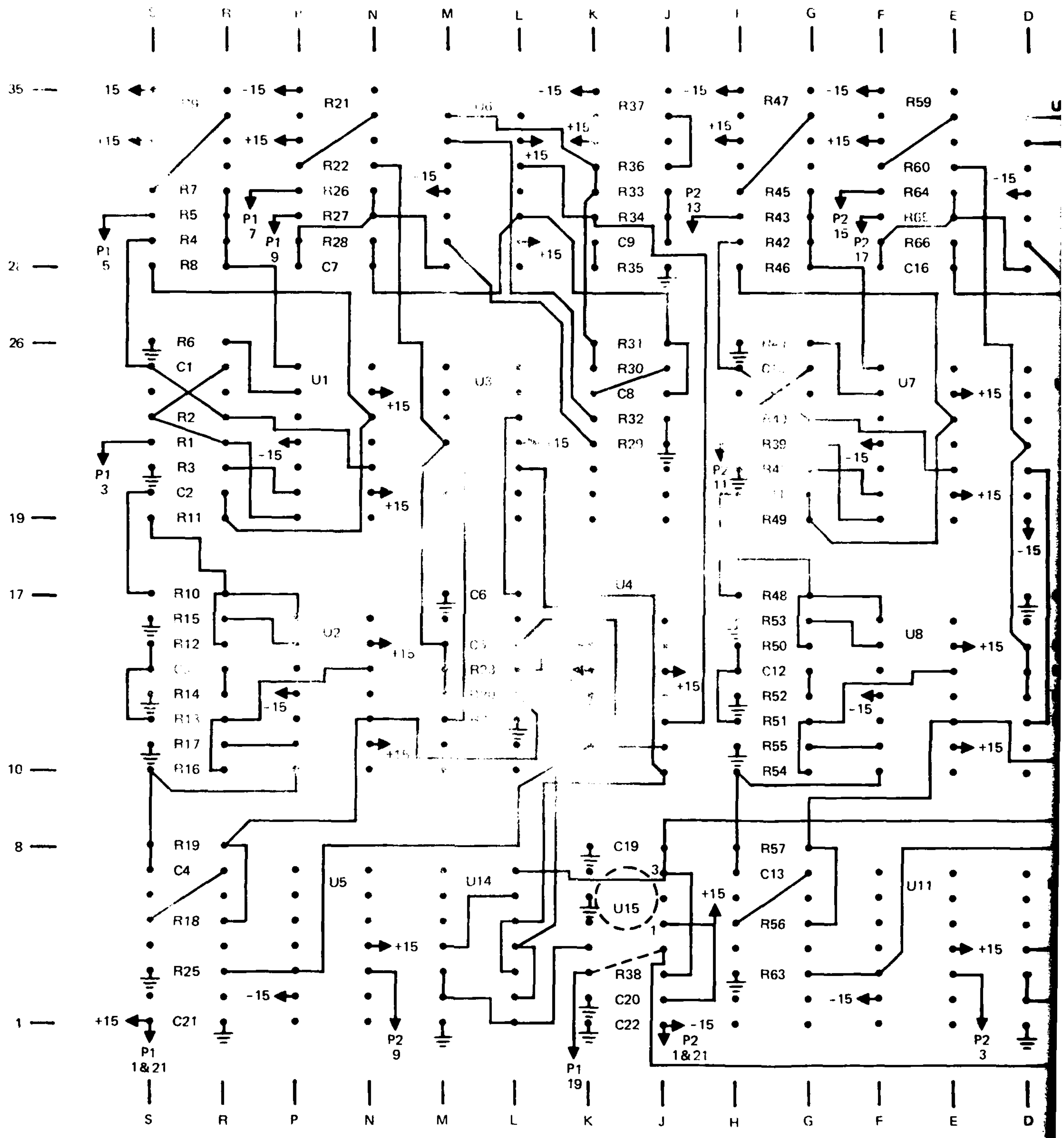


Figure 9. Compensation card schematic



COMPONENT SIDE

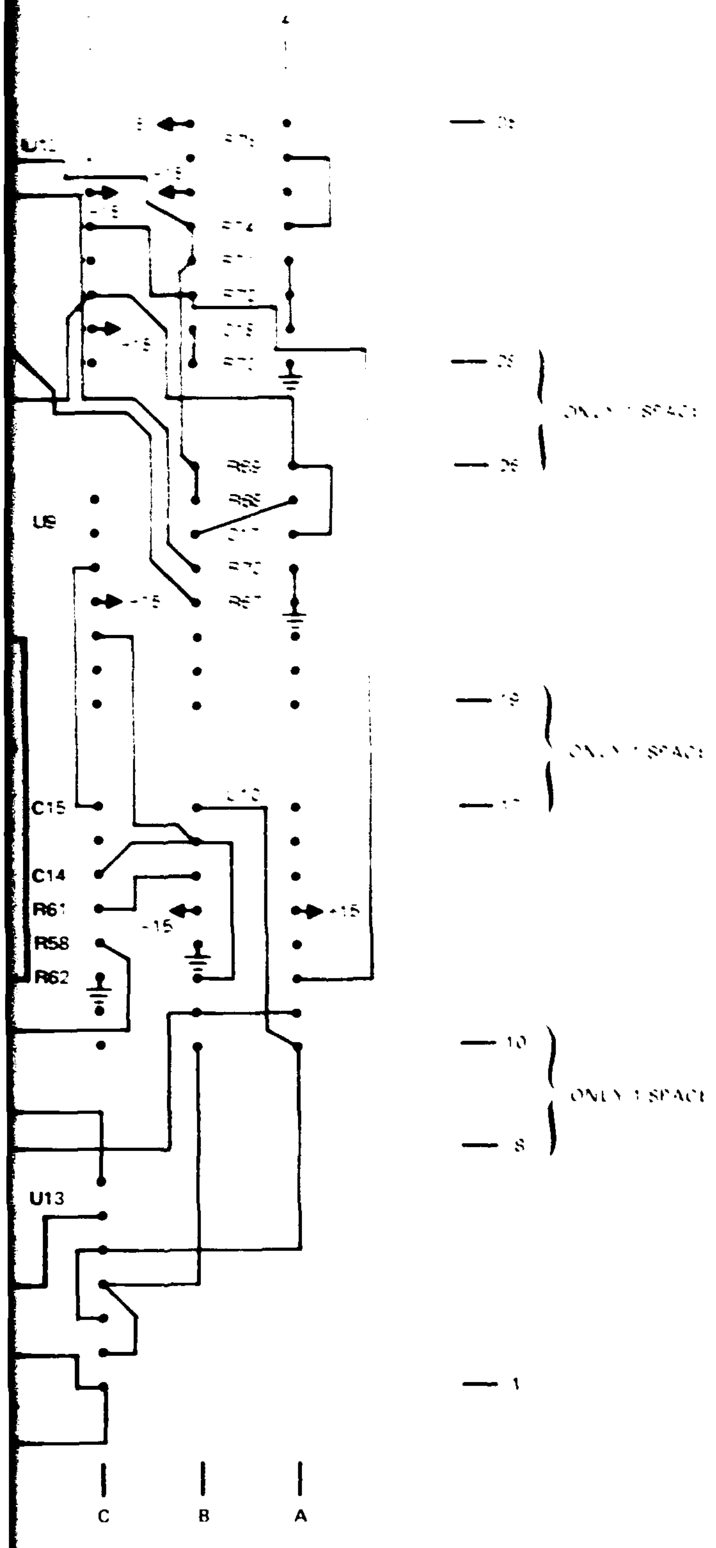


Figure 10. Compensation card interconnection diagram

Item	Quantity	Part Number, Value		Manufacturer	Nomenclature
C4, C13	2	Red cap	4.4 μF	ERIE	Capacitor
C7	1	CK06	0.22 μF		Capacitor
C8	1	CK05	0.082 μF		Capacitor
C9	1	CK06	0.33 μF		Capacitor
R1, R39	2	RC07	5.1K		Resistor
R2, R40, R68	3	RC07	2.4K		Resistor
R5	1	RC07	3K		Resistor
R10, R30, R48	3	RC07	24K		Resistor
R11, R31, R49, R69	4	RC07	100K		Resistor
R12, R13, R18, R33, R34	10	RC07	51K		Resistor
R14, R35, R52	3	RC07	6.2K		Resistor
R16, R19, R54, R57	4	RC07	200K		Resistor
R26, R27	2	RC07	18K		Resistor
R43	1	RC07	10K		Resistor
R64, R65	2	RC07	20K		Resistor

Table 5. 5-inch platform compensation card component changes.

2. Demodulator Card

The demodulator card is shown in figure 11. In the card's initial fabrication, dual in-line integrated circuits and discrete components were used. However, Honeywell now has a hybrid package available, as shown in figure 11. The unit is a quadrature demodulator. It provides the necessary signal conditioning for the MHD rate sensor in the feedback loop that will be discussed in the electronics section. The demodulator card is inserted into the second slot provided in the card cage (X2). Figure 12 is a schematic of the demodulator; figure 13 is the interconnection diagram; and table 6 is the parts list.

3. MHD Driver Card

The MHD driver card is shown in figure 14. (The MHD driver is the source of power for the MHD.) The MHD driver card provides two-phase, 400-hertz, 26-volt rms power to drive the MHD rotor. The driver is an integrated circuit servoamplifier fabricated by Inland Motors Inc. The GYRO switch on the control panel provides +28 Vdc to power this servoamplifier. Dual in-line integrated circuits and discrete components form the 400-hertz generator that drives the servoamplifier. The MHD driver card is inserted in the third slot provided in the card cage (X3). Figure 15 is a schematic drawing of the MHD driver, and table 7 is the parts list. Figure 16 is an interconnection diagram of the MHD driver.

4. Servoamplifier Card

The servoamplifier card is shown in figure 17. This card is only used with the 5-inch antenna platform. The current drivers (see next section) are not used for the 5-inch magnetic particle clutch/motor-driven antenna platform. The servoamplifier card is used to drive the magnetic particle clutches, power for which is provided by a 28-volt motor. This 28-volt

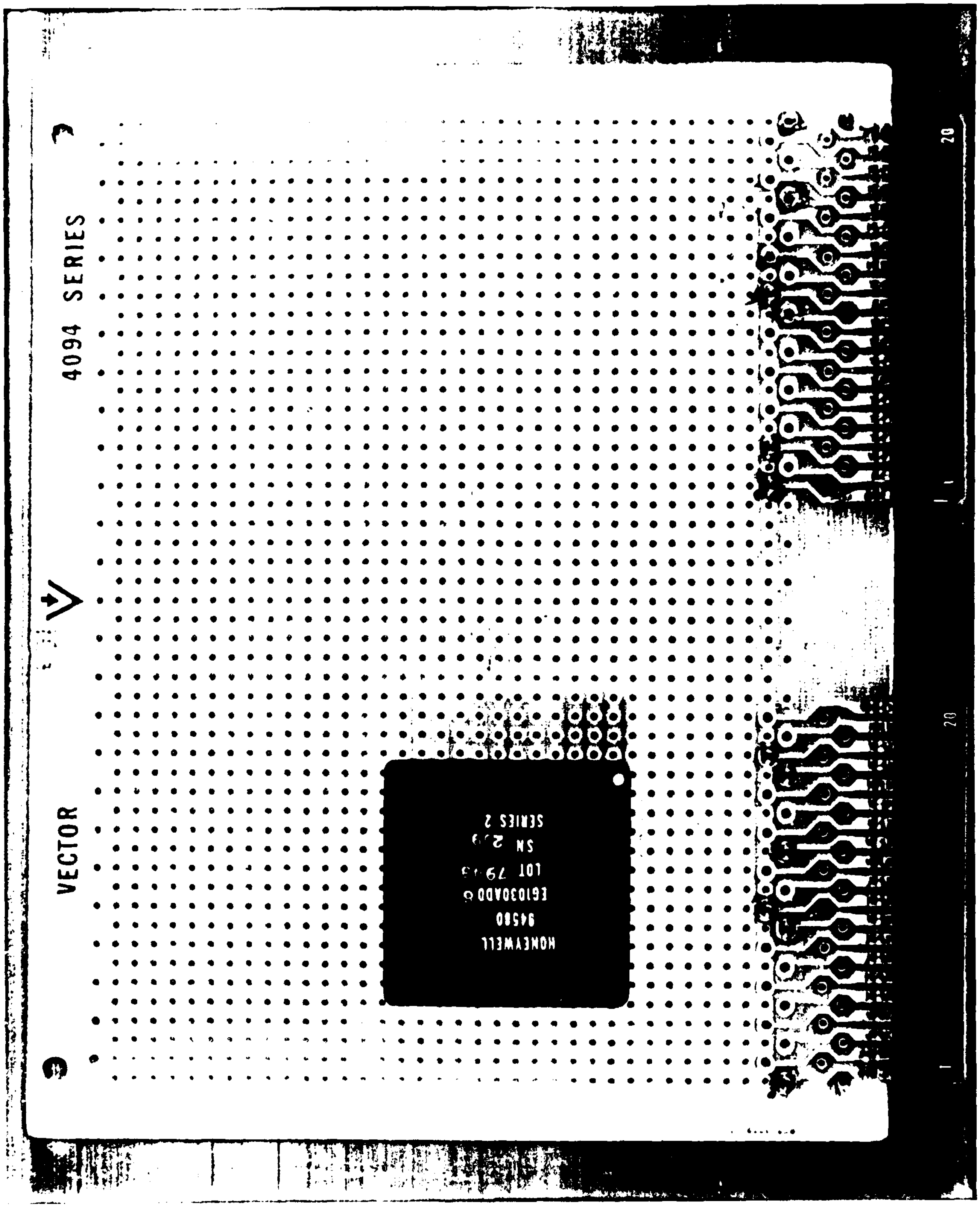
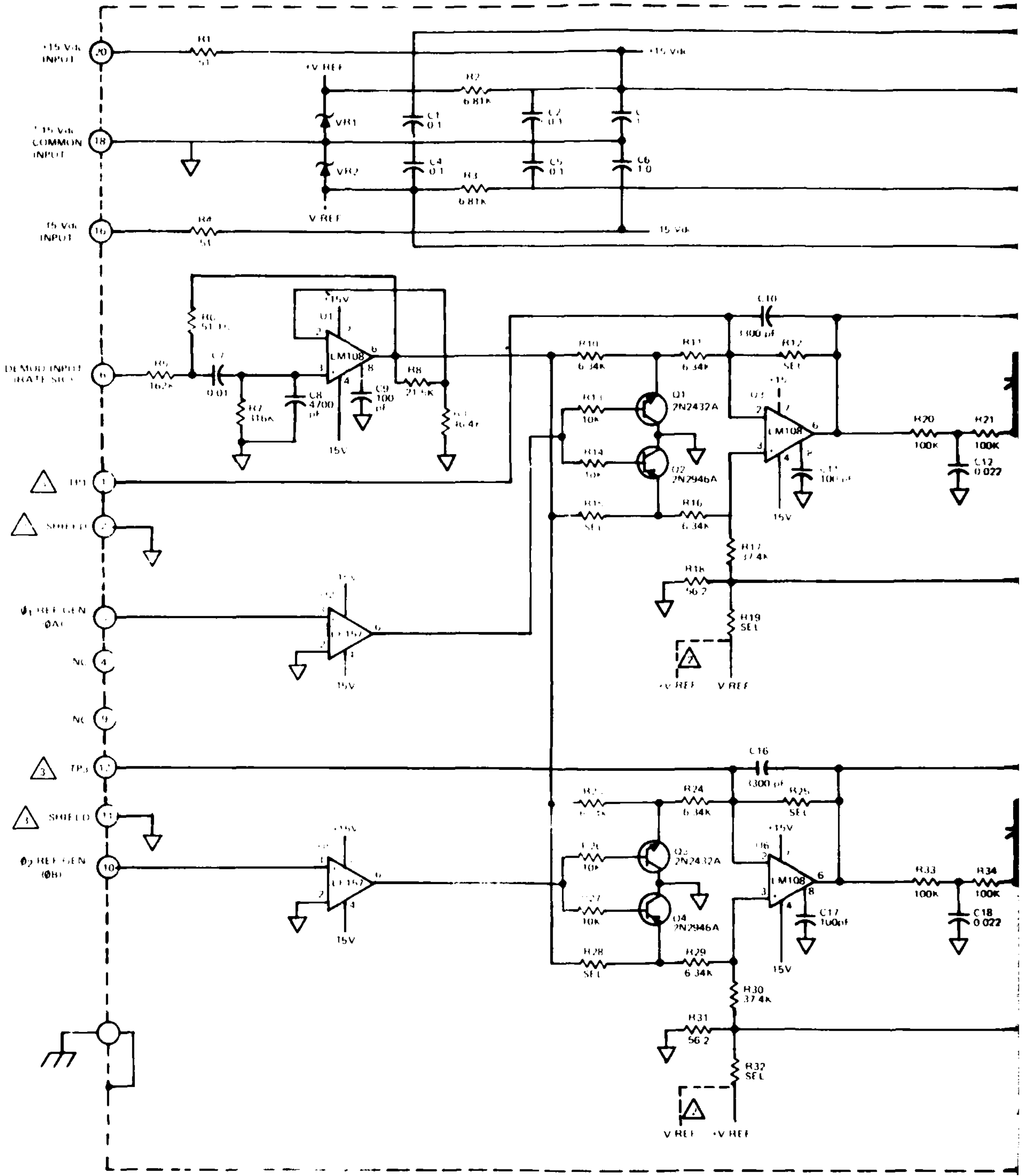


Figure 11. Demodulator card.



1. TEST POINTS NOT ACCESSIBLE ON SERIES 1
2. ALTN OFFSET CONFIGURATION
1. ALL RESISTANCES ARE IN OHMS AND ALL CAPACITANCES ARE IN μF UNLESS OTHERWISE SPECIFIED

HIGHEST REFERENCE DESIGNATION USED				
C21	Q4	R35	U7	VR2

Figure 17 Demodulator schematic

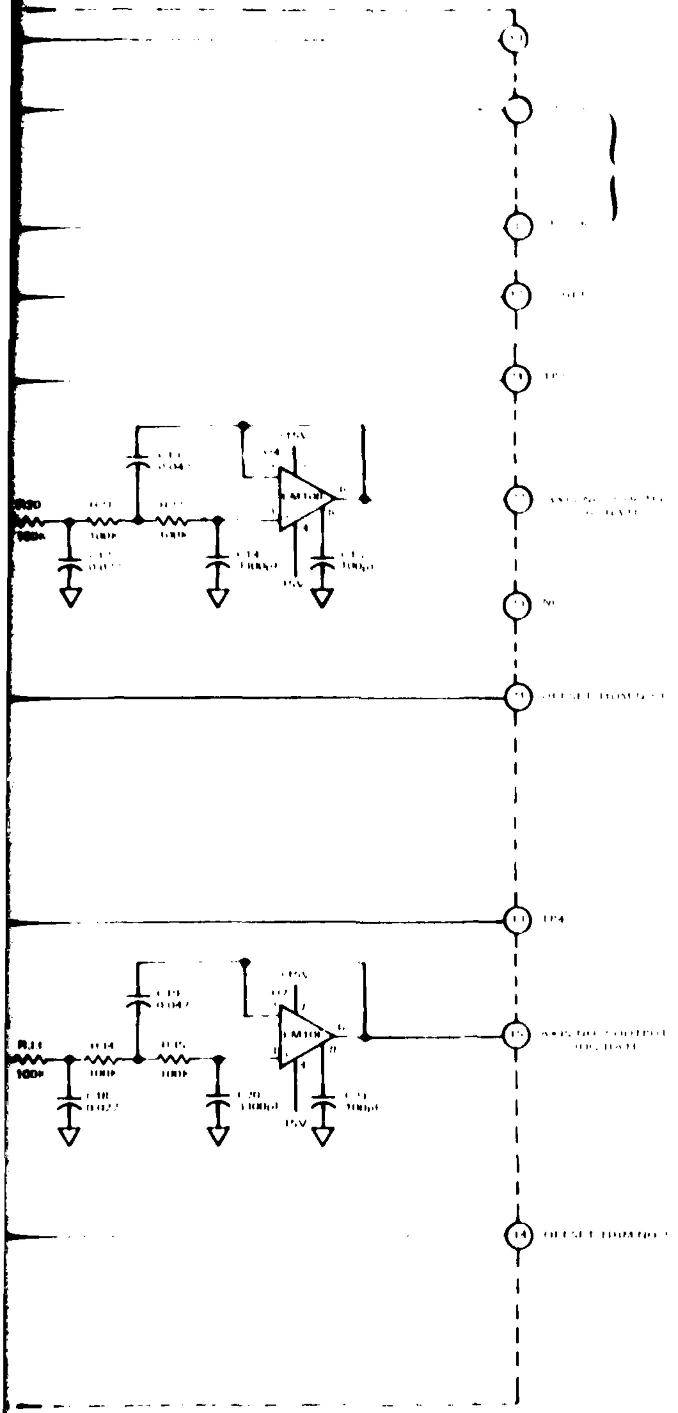


Figure 12. Demodulator schematic.

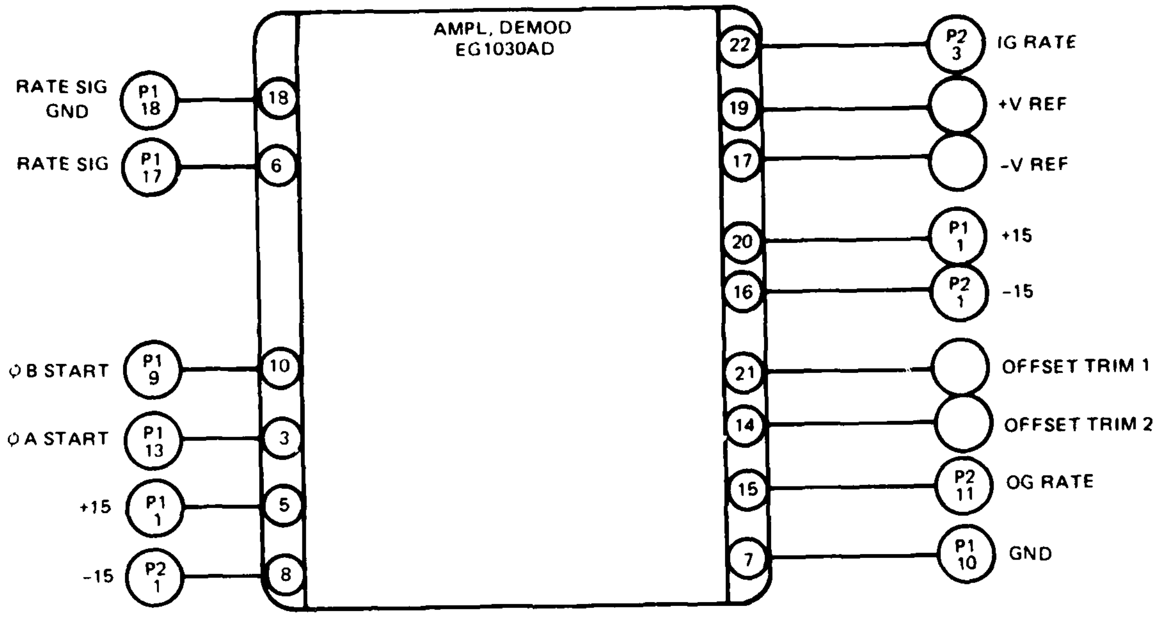


Figure 13. Demodulator interconnection diagram.

Item	Quantity	Part Number	Manufacturer	Nomenclature
U1	1	EG1030AD06	Honeywell	Hybrid demodulator
XPC-1	1	4094	Augat	Vector board

Table 6. Demodulator parts list.

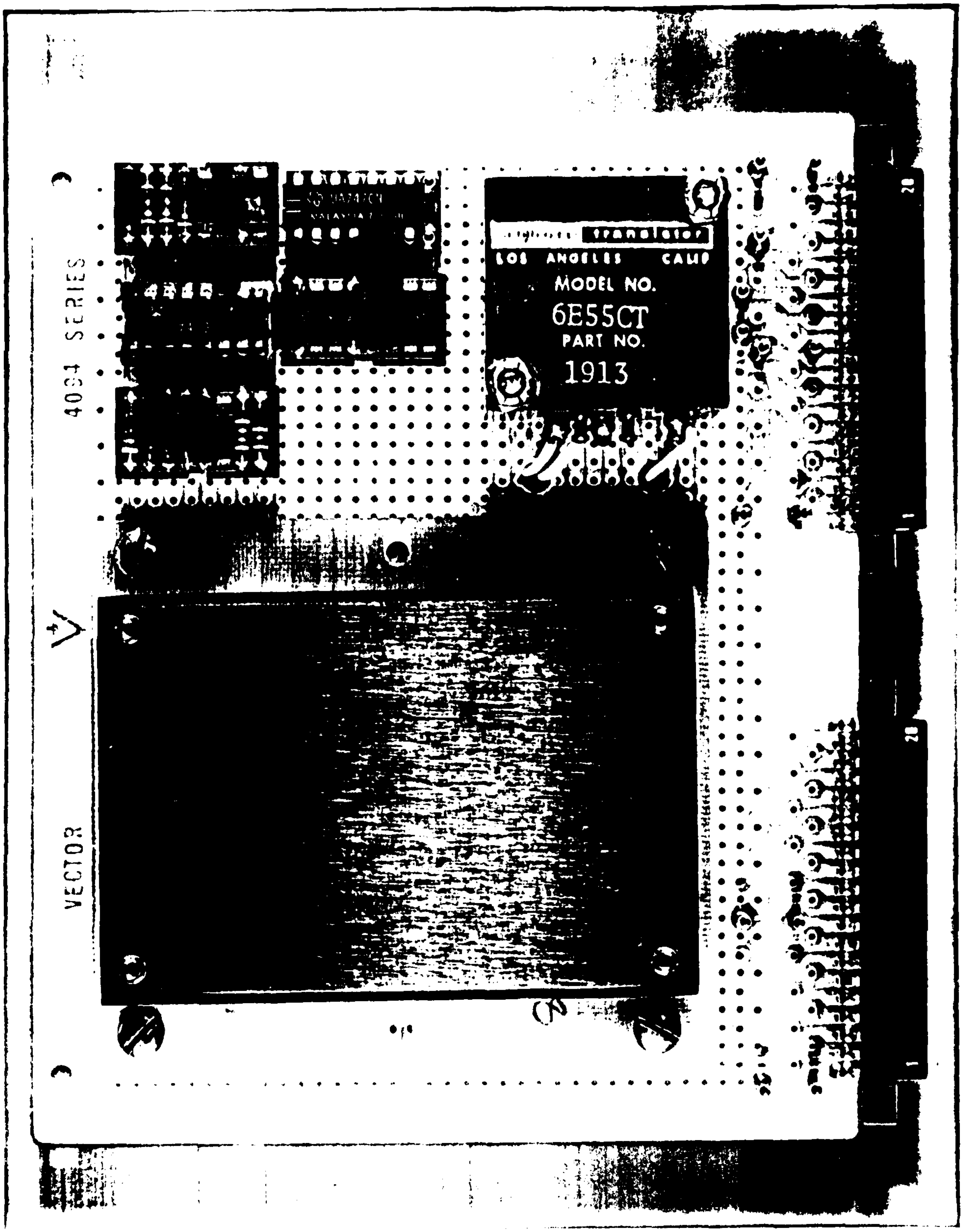


Figure 14. MHD driver.

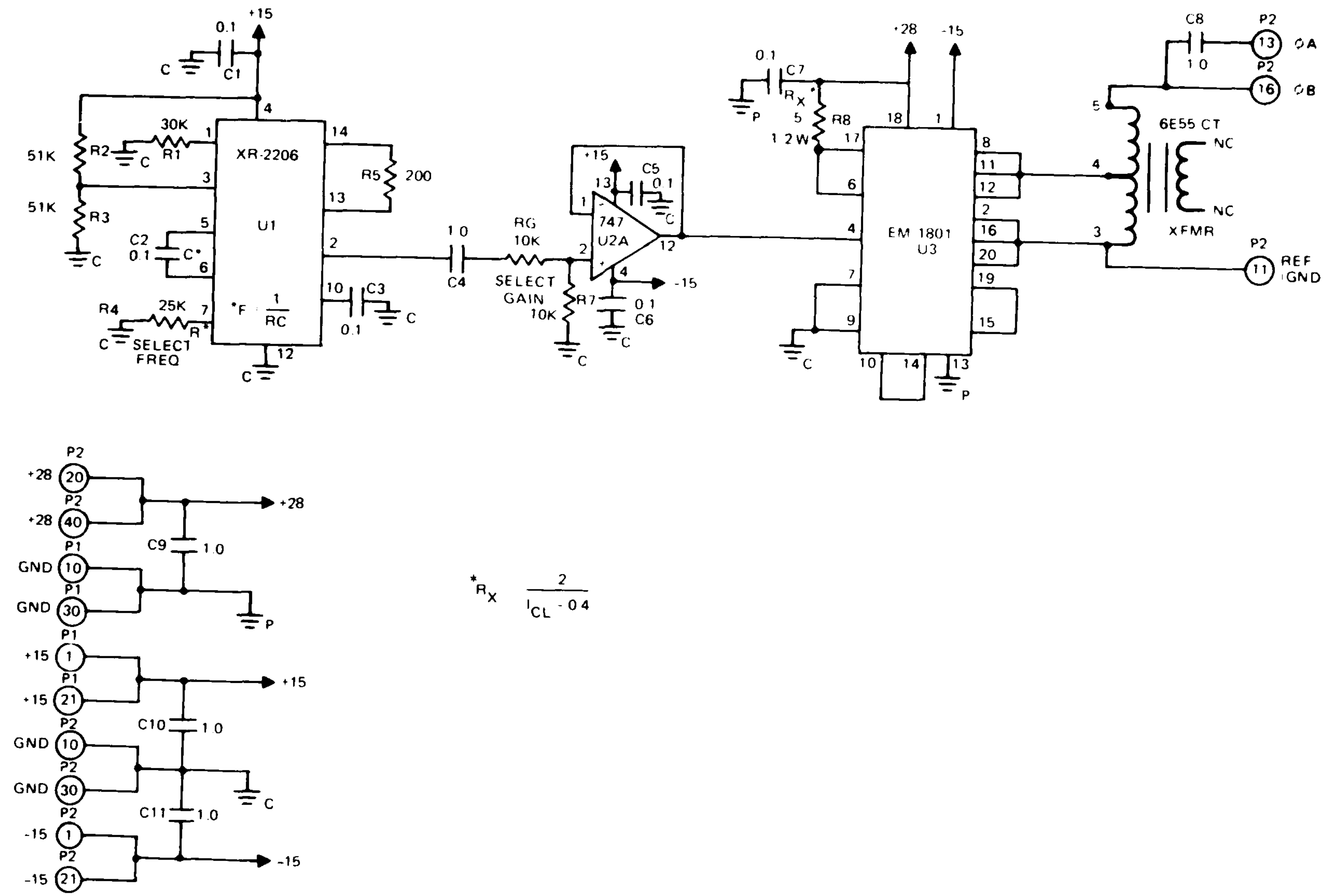


Figure 15. MHD driver schematic.

Item	Quantity	Part Number, Value		Manufacturer	Nomenclature
C1, C2, C3, C5, C6, C7	6	CK06	0.1 μF		Capacitor
C4, C8, C9, C10, C11	5	CK06	1.0 μF		Capacitor
R1	1	RC07	30K		Resistor
R2, R3	2	RC07	51K		Resistor
R4	1	RC07	25K (select)		Resistor
R5	1	RC07	200		Resistor
R6, R7	2	RC07	10K		Resistor
R8	1	1 2W	5		Resistor
T1	1	6E55CT		Abbott	Transformer
U1	1	XR-2206		R-OHM Corp	IC, function gen
U2	1	74747		Texas instrument	IC, op amp
U3	1	EM1801		Inland	IC, servoamp
S1	1	SO1801		Inland	IC socket

Table 7. MHD driver card parts list.

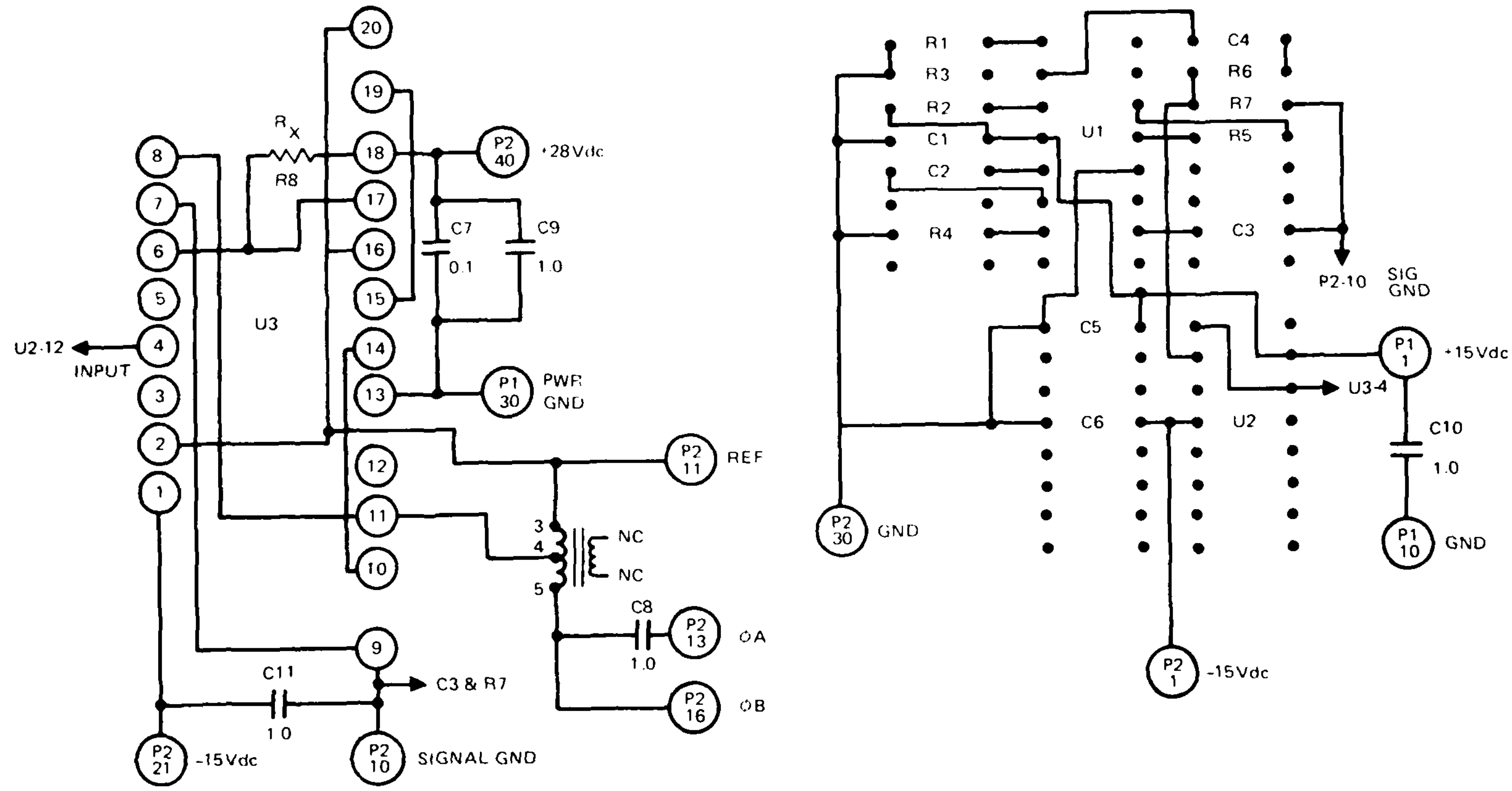


Figure 16. MHD driver interconnection diagram.

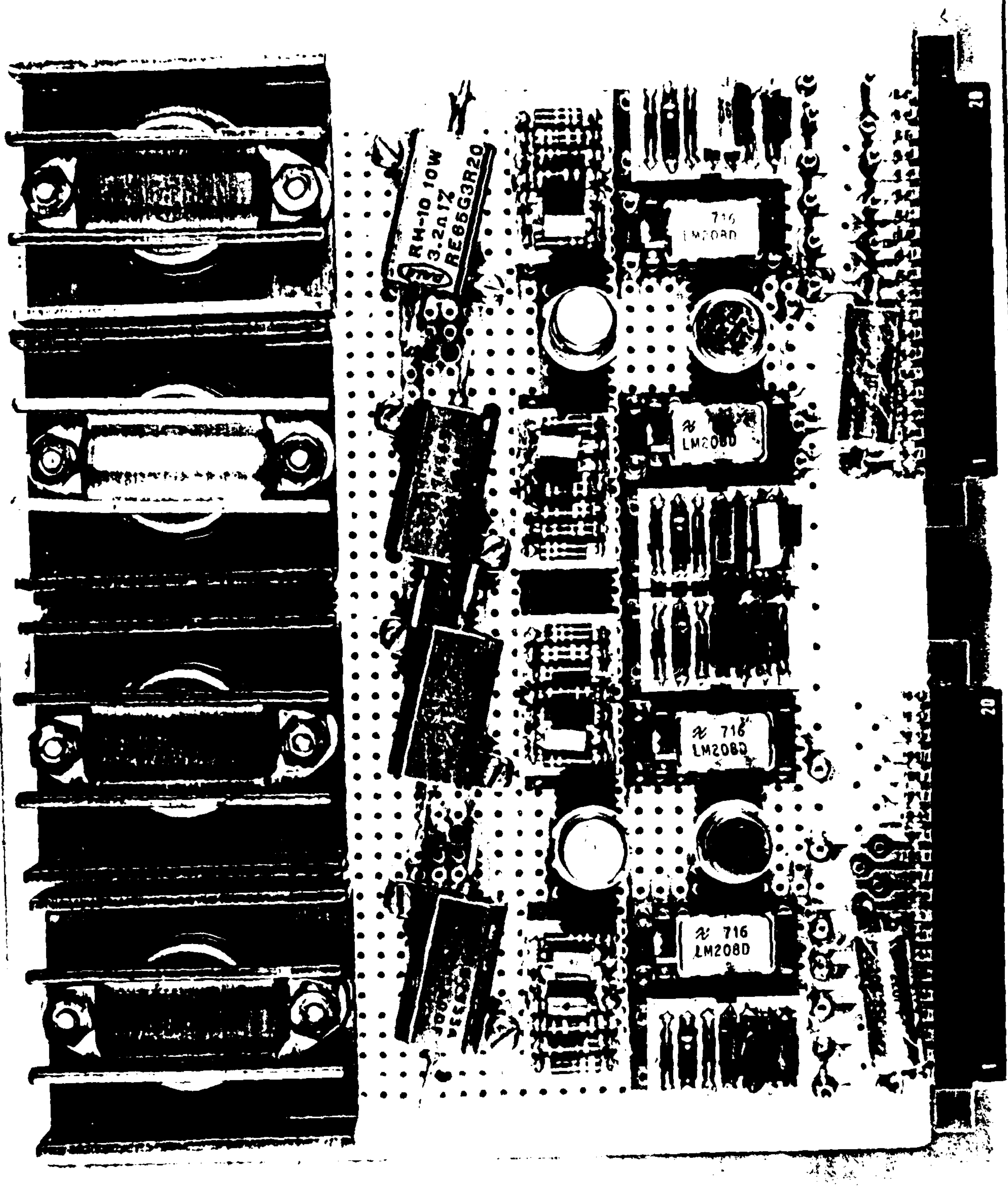


Figure 17. Servoamplifier card.

power is controlled by the torque motor switch on the control panel. The electronic design for this card will not be discussed in the electronics section, since the main objective of this document is to discuss the 10-inch antenna platform. However, it is important to note that this card cage is universal for the two platforms, and that the necessary component changes for operation of the 5-inch antenna platform are pointed out in the former electrical design sections (the compensation card only). The servoamplifier card is inserted in the fourth slot of the card cage (X4). Figure 18 is a schematic of the servoamplifier card and table 8 is the parts list.

5. Current Drivers

Figure 19 shows the inner and outer gimbal current drivers for the torque motors of the 10-inch antenna platform. The TORQUE switch on the control panel places +28 Vdc on the current drivers to activate them. The current drivers are mounted on a plate attached to the outside of the card cage. An extender card and cable are used to provide a wiring harness from the fifth slot of the card cage (X5) to the current drivers. Note that the current drivers are current-limited to protect the torque motors as well as the current drivers themselves. The current-limiting resistor (R_X) is determined by the equation

$$R_X = \frac{2}{I_{CL} - 0.4}$$

where I_{CL} is the limiting current. The current drivers are integrated-circuit servoamplifiers fabricated by Inland. They are mounted by means of sockets and attached to heat sinks for easy replacement. Figure 20 is a simplified schematic; table 9 is the parts list; and figure 21 shows current driver interconnections.

D. 10-inch ANTENNA PLATFORM

Figure 22 shows the 10-inch antenna platform. The primary design features of the platform are the adaptability to other antennas, the large volume and weight capability, and the low-cost design. The modular construction technique of the platform allows adaptation to a variety of antennas without complete redesign. The platform is a bail-ring concept with a high torque-to-inertia design. The bail-ring concept allows large load volume on the gimbals. A roller suspension system is used to hold the bail ring. This concept keeps the costs of production down. Torque motors were used for the inner and outer gimbal drives to achieve a high torque-to-inertia ratio at a low cost. This high torque-to-inertia concept also reduces costs by eliminating the requirement of designing balanced loads. Conductive plastic potentiometers were used because of their superior durability. The Honeywell MHD rate sensor is used for track-loop stabilization. The MHD is a new-concept, subminiature, high-performance, two-axis rate sensor specifically designed for large-volume producibility. It has been qualified to environmental requirements of MIL-STD-810B for gyros installed in fixed-wing aircraft, helicopters, and missiles. It is ideally suited for tactical missile seeker head stabilization. Figure 23 is the platform wiring diagram and table 10 is the parts list (which includes only the electronics). A limited set of drawings is provided below in the mechanical drawings section.

The antenna was designed and fabricated by AIL, Deer Park, Long Island, New York.

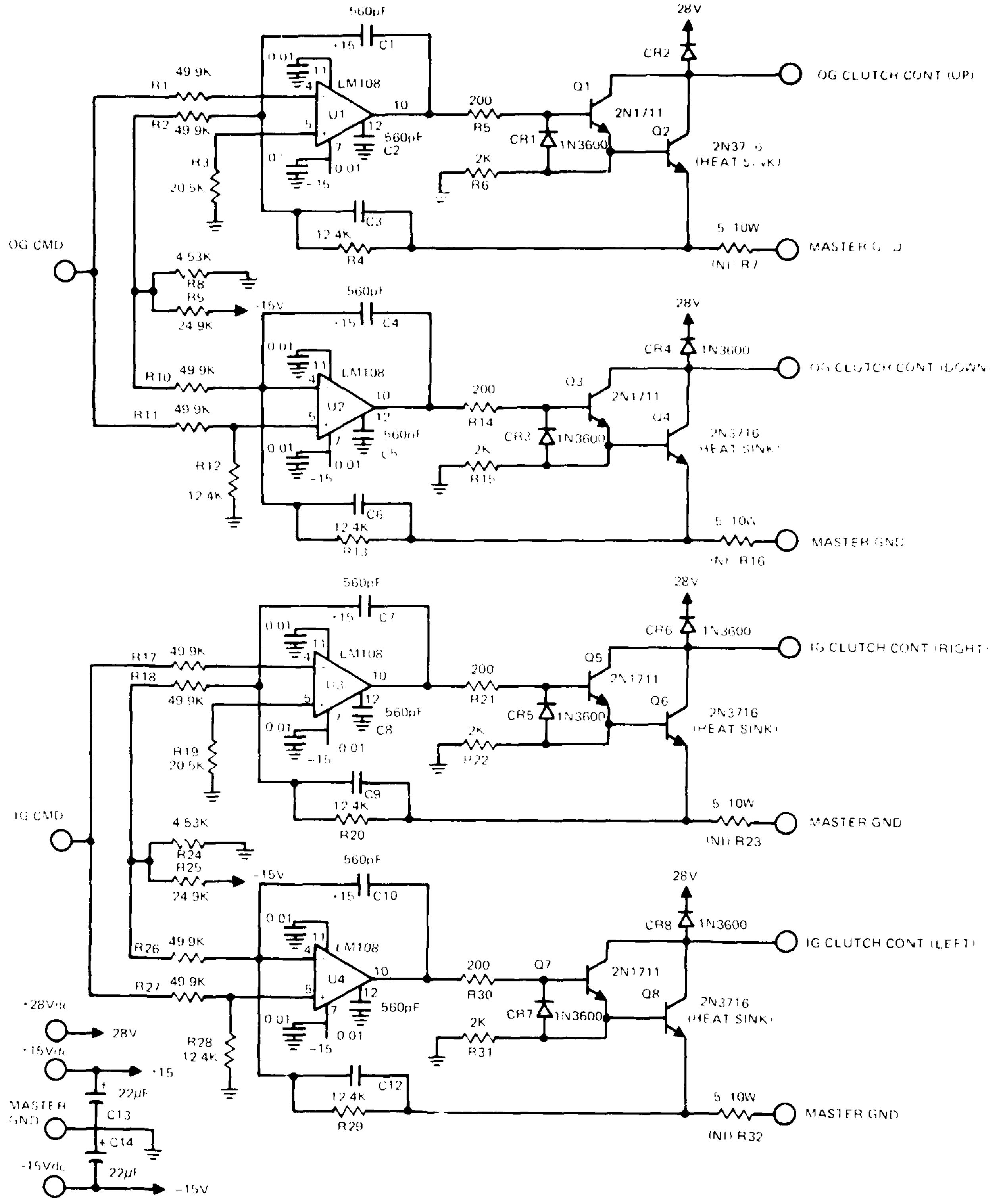


Figure 18. Servoamplifier schematic.

Item	Quantity	Part Number, Value		Manufacturer	Nomenclature
R1, R2, R10, R11, R17, R18, R26, R27	8	49.9K	0.1W, 1%		Resistor
R3, R19	2	20.5K	0.1W, 1%		Resistor
R4, R12, R13, R20, R28 R29	6	12.4K	0.1W, 1%		Resistor
R5, R14, R21, R30	4	RC07	100		Resistor
R6, R15, R22, R31	4	RC07	2K		Resistor
R7, R16, R23, R32	4	RE65N5R00F 5, 10W			Resistor
R8, R24	2	4.53K	0.1W, 1%		Resistor
R9, R25	2	24.9K	0.1W, 1%		Resistor
C1, C2, C4, C5, C7, C8, C10, C11	8	CK05	560 pF		Capacitor
C3, C6, C9, C12	4	CK05	0.01 F		Capacitor
C13, C14	2	CS13	22 μF, 35V, 10%		Capacitor
CR1 through CR8	8	1N3600			Diode
Q1, Q3, Q5, Q7	4	2N1711			Transistor
Q2, Q4, Q6, Q8	4	2N3716			Transistor
H1 through H4	4	6105-B		Thermalloy	Heat sink
U1 through U4	4	LM108		Signetics	Integrated circuit

Table 8. Servoamplifier parts list.

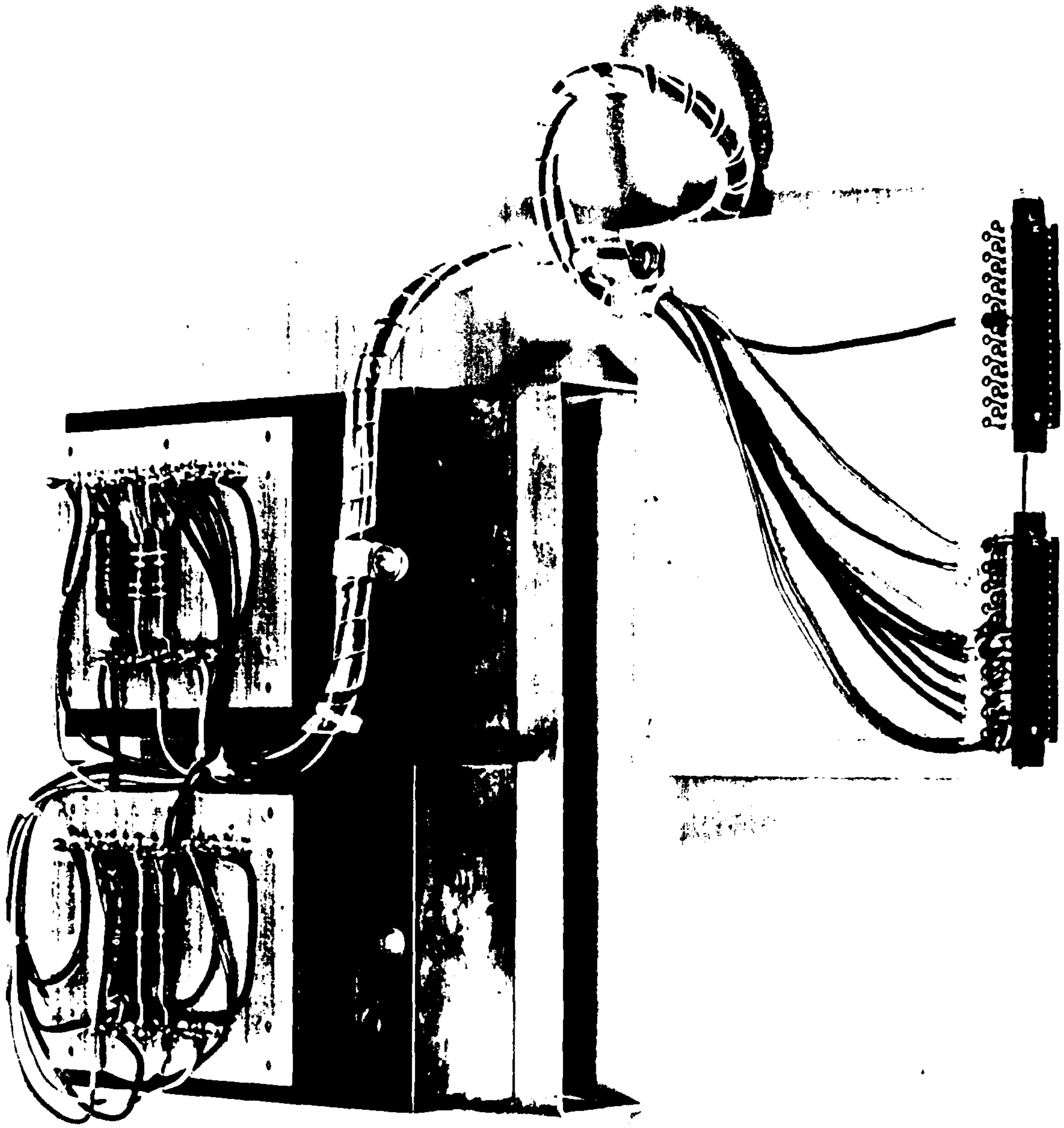


Figure 19. Current drivers.

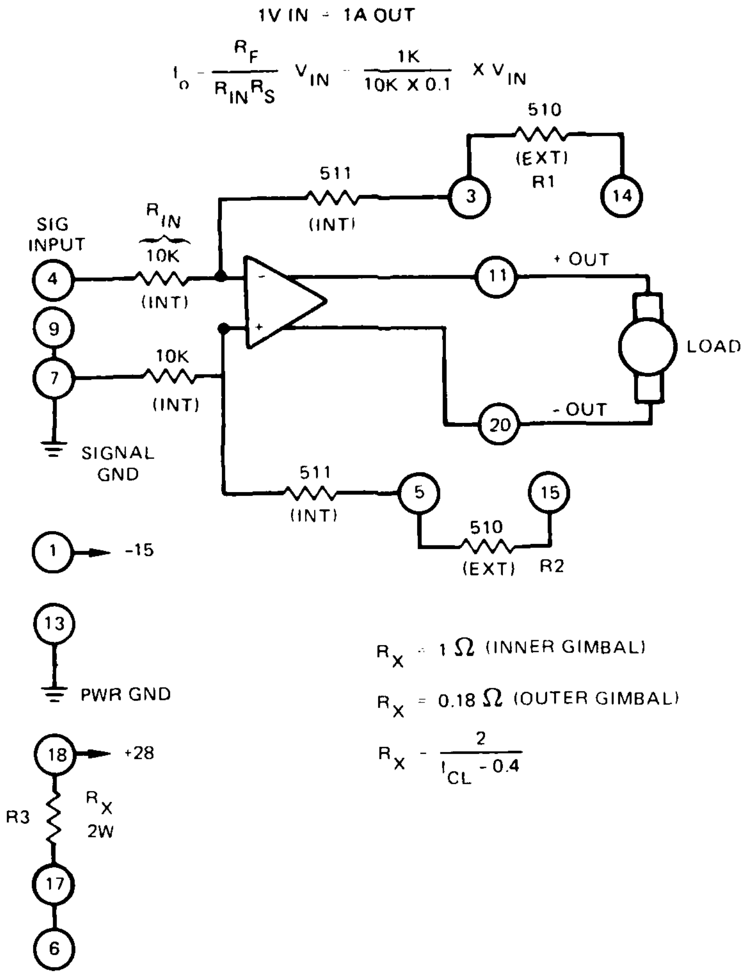
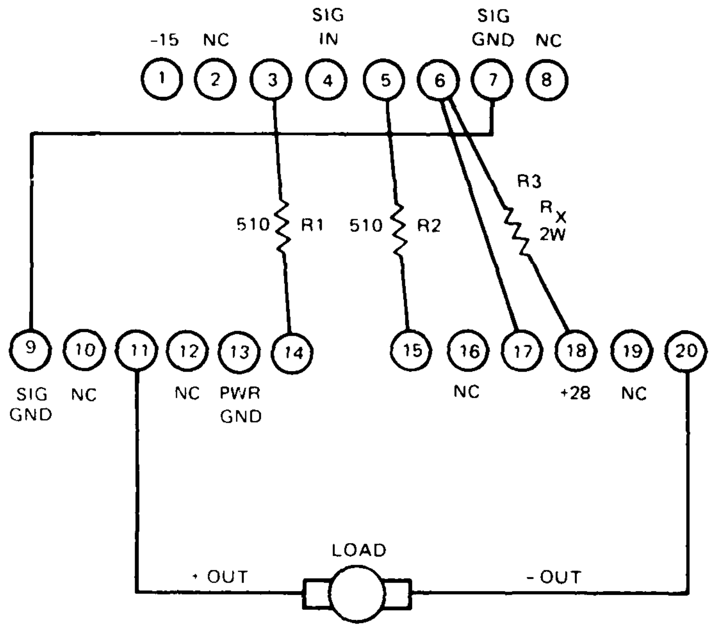


Figure 20. Current driver servoamplifier simplified schematic, outer and inner gimbal.

Item	Quantity	Part Number, Value	Manufacturer	Nomenclature
R1, R2	4	1/2W 510		Resistor
R3	1	2W 0.18		Resistor, OG
R3	1	2W 1		Resistor, IG
HS1	2	HS1801	Inland	Heat sink
U1	2	EM1802	Inland	IC, servoamp
	1	4094	Augat	*Vector board
	2	SO1801	Inland	IC socket

*Vector board used as extender and cable connector.
NOTE: Parts list applies only to one current driver.

Table 9. Current driver parts list (outer and inner).



R_X 1 Ω (INNER GIMBAL)

R_X 0.18 Ω (OUTER GIMBAL)

$$R_X \quad \frac{2}{I_{CL} - 0.4}$$

1U IN 1A OUT

$$I_o \quad \frac{R_F}{R_{IN} R_S} V_{IN} \quad \frac{1K}{10K \times 0.1} \times V_{IN}$$

Figure 21. Current driver servoamplifier interconnections.

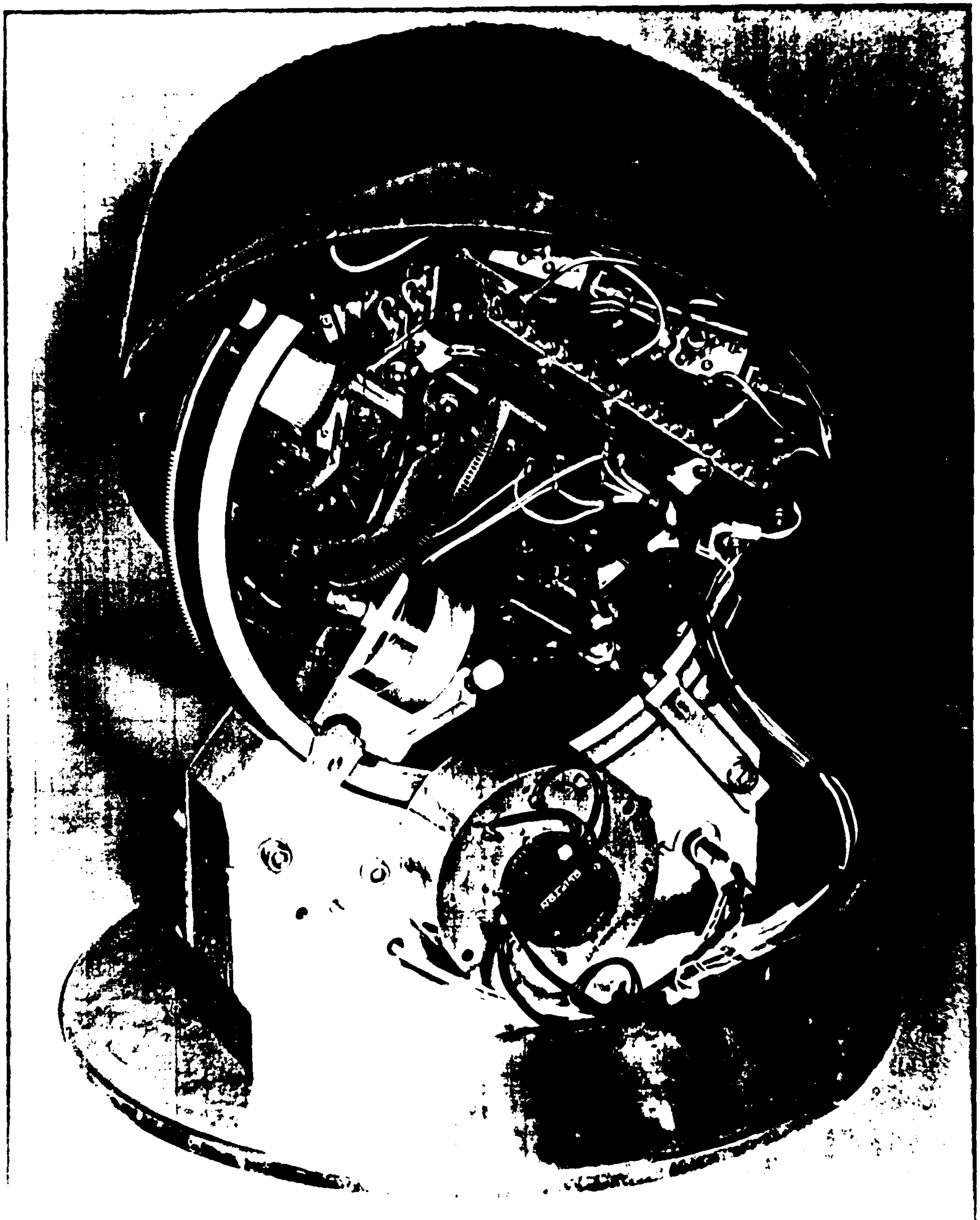


Figure 22 10-inch antenna platform.

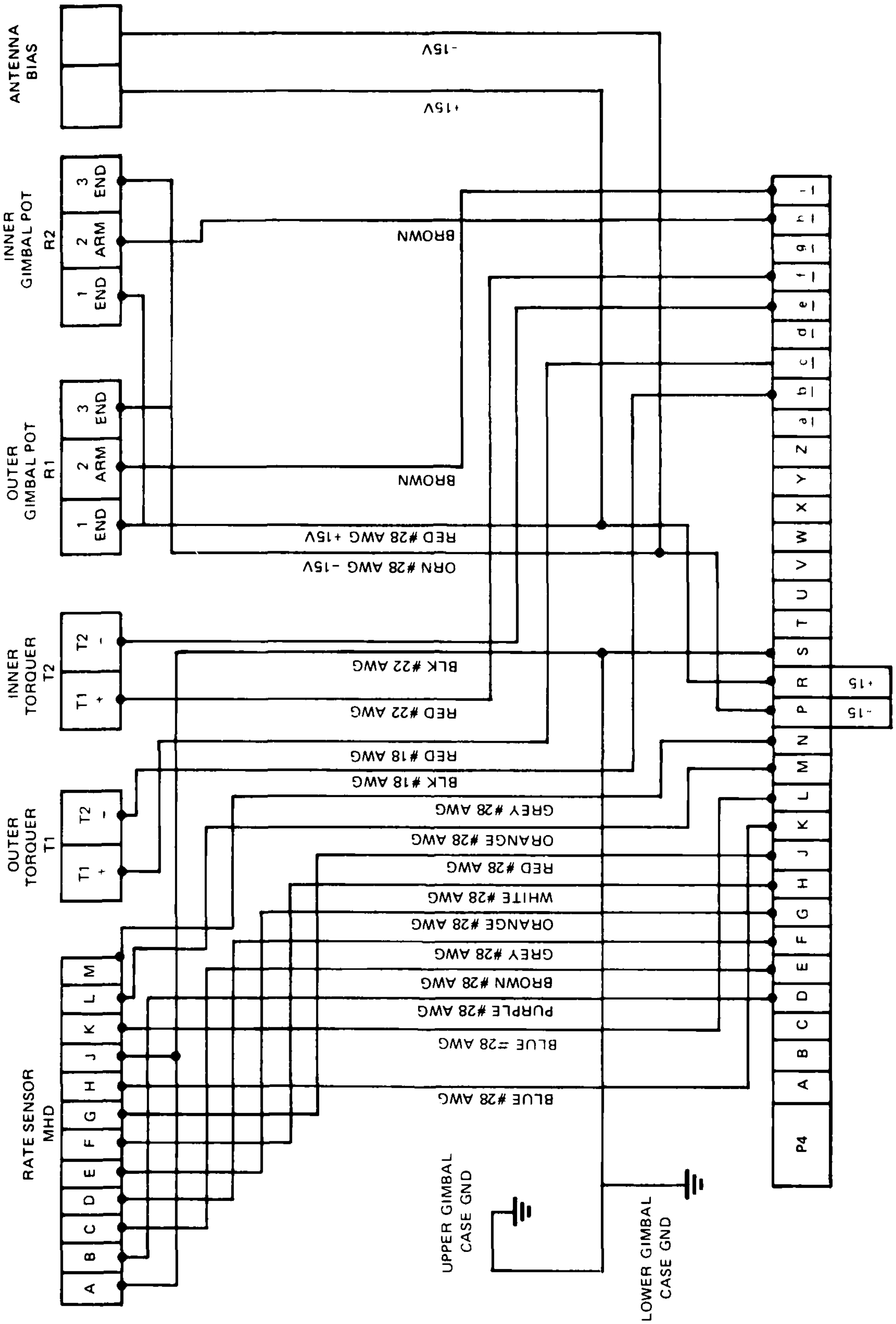


Figure 23. 10-inch platform wiring diagram.

Item	Quantity	Part Number	Manufacturer	Nomenclature
G-P1	1	PTO2SE-20-39SY	Bendix	Connector
MHD	1	GG2500LC03	Honeywell	Rate sensor (MHD)
T1	1	DPH3320-A-17	Clifton	Torque motor
T2	1	DPH1990-B-2T	Clifton	Torque motor
R1	1	3571S-1-502	Bourns	Potentiometer (5K)
R2	1	78SF1C502	New England Instruments	Potentiometer (5K)
	1	E001-01-040	AIL	Antenna/processor

Table 10. 10-inch antenna platform parts list (electronics only).

E. 5-inch ANTENNA PLATFORM

Figure 24 shows the Hughes antenna platform, which is included here for documentation purposes only. The platform is a bail ring concept with magnetic particle clutch servos to drive each gimbal. Permanent magnet dc motors provide the mechanical power input to the clutches. The platform has inner and outer gimbals for positioning, and an MHD rate sensor for track loop feedback stabilization. Figure 25 is the platform wiring diagram.

III. ELECTRONIC DESIGN

The electronic design section illustrates the derivation of the compensation and feedback networks. (The compensation transfer functions are derived in reference 1.) This section also shows how to match the electronics to the above transfer functions. The torque motors, gear ratios, and inertial load factor are not covered in this section because these are considered fixed in determining the compensation transfer functions (see reference 1).

A. SLAVE LOOP

A slave loop is implemented about each gimbal by utilizing feedback from a gimbal-driven potentiometer. The slave servosystem has the function of pointing the antenna toward the target prior to activation of the target-tracking system. The slave loop commands are originated by an outside source in gimbal coordinates. Figure 26 illustrates the slave loop block diagram. The motor/amplifier/load is derived in reference 1 and is considered as given. The compensation required to close the slave loop is discussed in this section. Figure 27 is a simplified schematic of the slave loop compensation and table 11 presents component values. A boresight adjustment is located in the compensation card to permit zeroing the antenna platform at boresight.

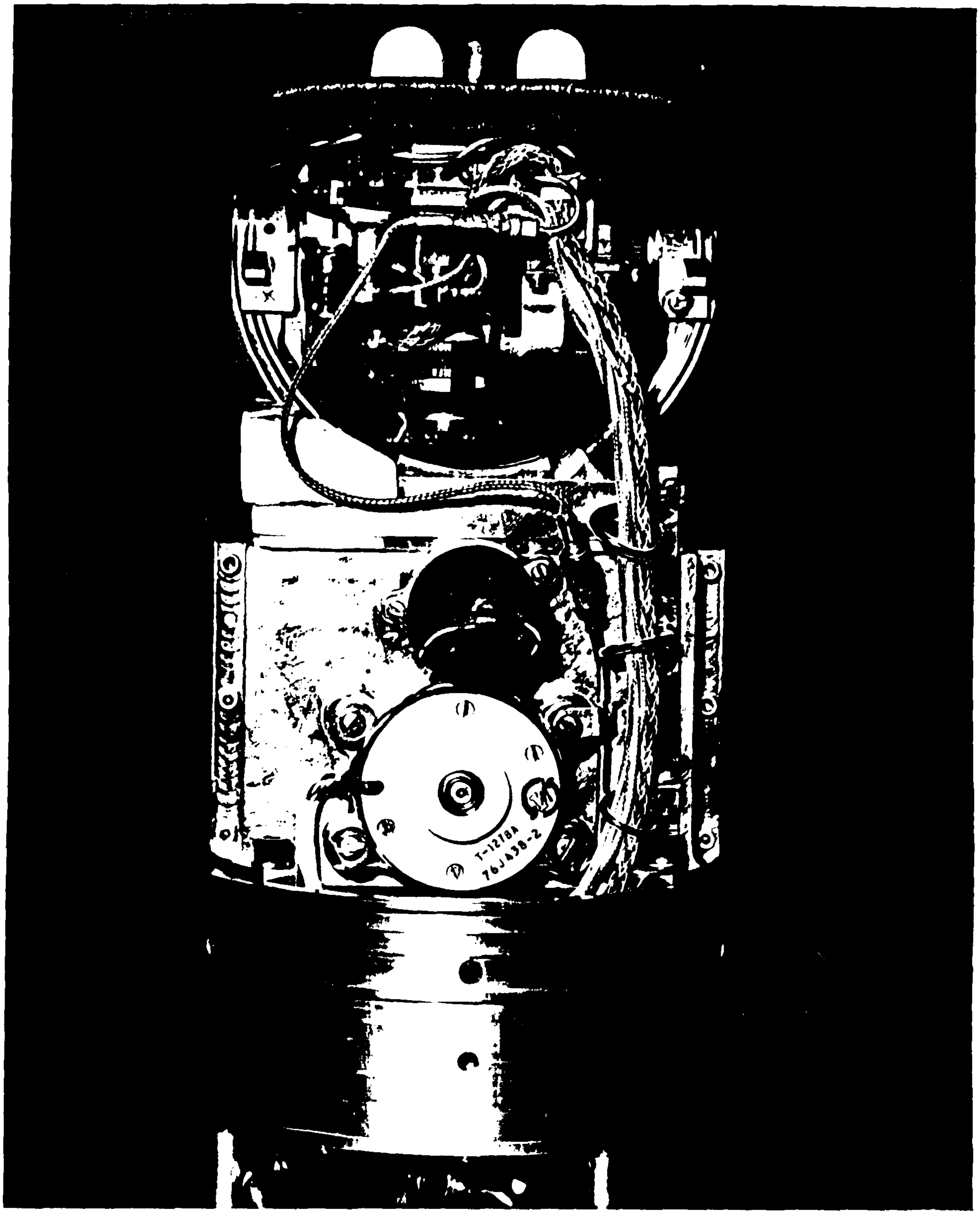


Figure 24. 8-inch antenna platform

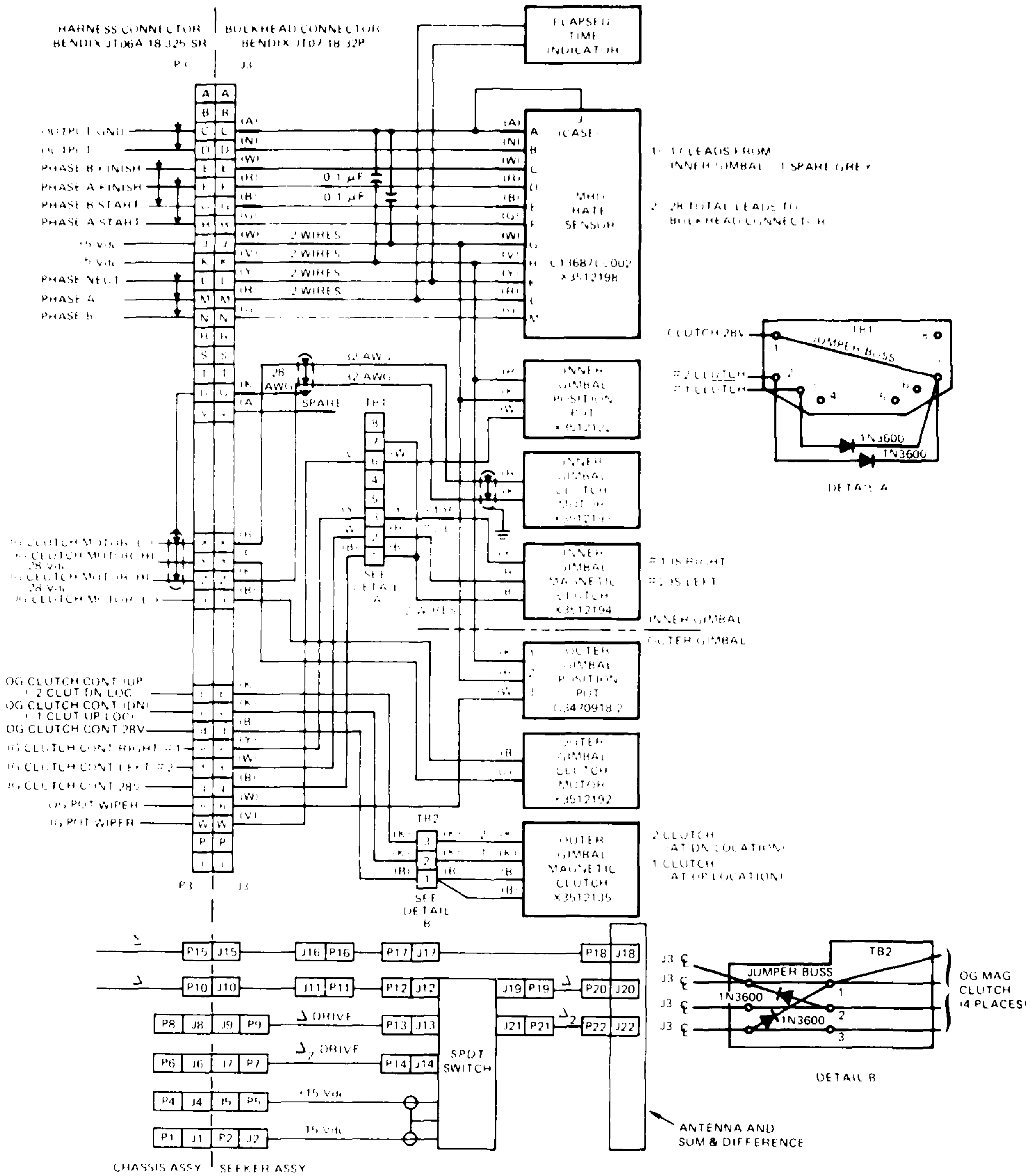


Figure 25. 5-inch antenna platform wiring diagram.

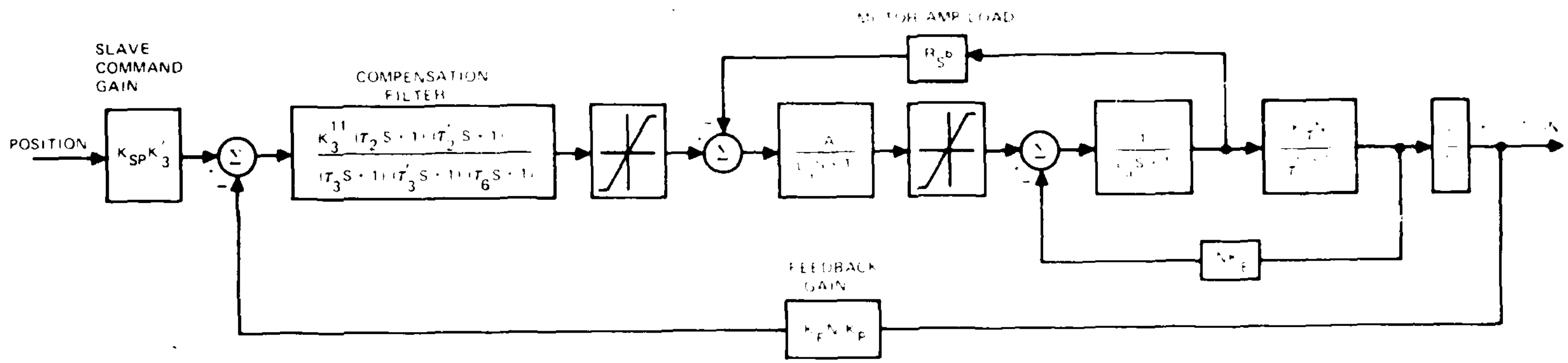


Figure 26. Slave loop block diagram.

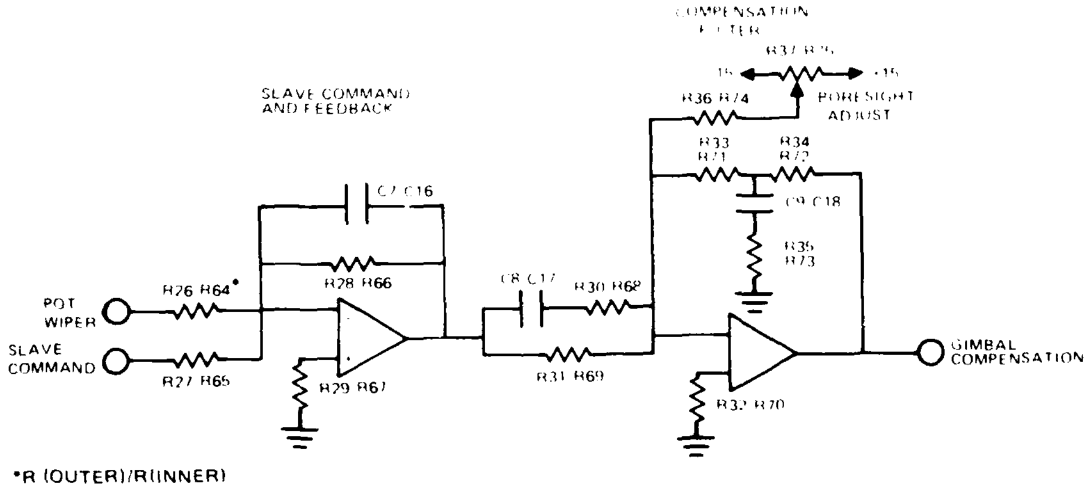


Figure 27. Slave loop compensation.

Inner Outer Components	Inner Gimbal	Other Gimbal
R64 R26	18K	30K
R65 R27	47K	39K
R66 R28	160K	160K
R67 R29	16K	16K
R68 R30	24K	6.8K
R69 R31	160K	82K
R70 R32	82K	39K
R71 R33	82K	39K
R72 R34	82K	33K
R73 R35	6.2K	1.5K
R74 R36	10M	10M
R75 R37	50K pot	50K pot
C16 C7	0.15 μF	0.182 μF
C17 C8	0.082 μF	0.22 μF
C18 C9	0.33 μF	1.0 μF

Table 11. Slave loop compensation component values.

1. Slave Command

Slave command gain (K_3^1) was determined by assuming a signal input of range ±5 volts for ±45-degree movement of the inner and outer gimbals. Thus the inner and outer slow-position gain (K_{SP}) is calculated as follows:

$$K_{SP} = \frac{10}{\pi/2} = 6.37 \text{ volts/radian.}$$

Referring to figure 27, we can see that the slave command gain (K_3^1) is calculated as follows:

$$K_3^1 = \frac{R28}{R27} = 4.10 \text{ volts/volt (outer gimbal)}$$

$$K_3^1 = \frac{R66}{R65} = 3.40 \text{ volts/volt (inner gimbal).}$$

The inner and outer gimbal gains differ because the gains in the respective slave loops differ. Total slave command gain is the product of the two gains (ie, $K_{SP}K_3^1$).

2. Feedback

The outer gimbal feedback potentiometer is of the three-turn type. A 30-volt potential is placed across the potentiometer; thus the potentiometer gain (K_p) can be calculated as follows:

$$K_p = \frac{30}{6\pi} = 1.59 \text{ volts/radian (outer gimbal).}$$

The ratio (N^1) of the outer gimbal movement with respect to the potentiometer is 8.5:1.

The inner gimbal feedback potentiometer is of the single-turn type. A 30-volt potential is also placed across this potentiometer; thus the potentiometer gain (K_p) can be calculated as follows:

$$K_p = \frac{30}{2\pi} = 4.78 \text{ volts/radian (inner gimbal).}$$

The ratio (N^1) of the inner gimbal movement with respect to the potentiometer is 3.0:1.

Referring to figure 27, we can see that the feedback gain K_F^1 can be calculated as follows:

$$K_F^1 = \frac{R28}{R26} = 5.33 \text{ volts/volt (outer gimbal)}$$

$$K_F^1 = \frac{R66}{R64} = 8.89 \text{ volts/volt (inner gimbal).}$$

Total feedback gain is the product of the three gains (ie, $K_F^1 N^1 K_p$). For feedback gain in reference 1 (K_F), the following relationships apply:

$$K_F = \frac{K_F^1}{K_3^1} = 1.30 \text{ volts/volt (outer gimbal)}$$

$$K_F = \frac{K_F^1}{K_3^1} = 2.61 \text{ volts/volt (inner gimbal).}$$

Note: The potentiometers used were of the high-precision, conductive plastic type because high feedback gain amplifies the crossover of the wirewound type.

3. Compensation

A lead-lag compensation network was necessary to provide the required stability. The transfer function for the slave loop compensation, per reference 1, is as follows:

$$\frac{K_3^2\,(\tau_2 S+1)(\tau_2^1 S+1)}{(\tau_3 S+1)(\tau_3^1 S+1)(\tau_6 S+1)} \; .$$

The calculations of the compensation gain (K_3^2) and the time constants (τ_2, τ_2^1, τ_3, τ_3^1, and τ_6) for both the inner and outer gimbals are shown in table 12. Note that for the compensation gain in reference 1 (K_3), the following relationships apply:

$$K_3 = K_3^1 K_3^2 = 3.60 \text{ volts/volt (outer gimbal)}$$

$$K_3 = K_3^1 K_3^2 = 3.49 \text{ volts/volt (inner gimbal)}$$

$$\frac{K_3^2\,(\tau_2 S+1)(\tau_2^1 S+1)}{(\tau_3 S+1)(\tau_3^1 S+1)(\tau_6 S+1)} \; .$$

B. TRACK LOOP

There are two loops involved in the tracking loop: the tracking loop itself and the stabilization loop. The tracking loop is closed by means of the reception of an emitting radar signal (via the antenna), which is processed to develop a line-of-sight rate ($\dot{\sigma}$) that is zeroed to allow automatic target tracking. The stabilization loop is provided as an inner loop in the tracking servosystem and is closed by means of the two-axis MHD rate sensor. This implementation causes the tracking loop error signals to be a measure of the inner and outer gimbal line-of-sight rates in inertially referenced coordinates. Figure 28 shows the track loop block diagram.

1. Compensation

Compensation consists of a processor filter, error/rate summer, and compensation filter. Figure 29 is a simplified schematic of the compensation filter, and table 13 presents the component values. The error/rate summer has a balance adjust to obtain the proper balance between track error and rate feedback (stabilization). There is also a boresight adjust in the compensation filter to zero the track error output to the antenna platform. A switch around the integrator of the compensation filter is used to discharge the integrator when in slave mode. Otherwise, in switching from slave to track, the charged capacitor would cause an instant jump.

<u>Outer Gimbal.</u>

$$K_3^2 = \frac{R33 + R34}{R31} = 0.880 \text{ volt/volt}$$

$$\tau_2 = (R30 + R31)\,C8 = 0.0195 \text{ second}$$

$$\tau_2^1 = R35 + \frac{R33 + R34}{4}\,C9 = 0.0195 \text{ second}$$

$$\tau_3 = (R30)\,C8 = 0.0015 \text{ second}$$

$$\tau_3^1 = (R35)\,C9 = 0.0015 \text{ second}$$

$$\tau_6 = (R28)\,C7 = 0.029 \text{ second}$$

<u>Inner Gimbal.</u>

$$K_3^2 = \frac{R71 + R72}{R69} = 1.025 \text{ volts/volt}$$

$$\tau_2 = (R68 + R69)\,C17 = 0.0151 \text{ second}$$

$$\tau_2^1 = R73 + \frac{R1 + R72}{4}\,C18 = 0.0156 \text{ second}$$

$$\tau_3 = R68\,C17 = 0.00197 \text{ second}$$

$$\tau_3^1 = R73\,C18 = 0.00205 \text{ second}$$

$$\tau_6 = R66\,C16 = 0.024 \text{ second.}$$

Table 12. Slave compensation filter calculations.

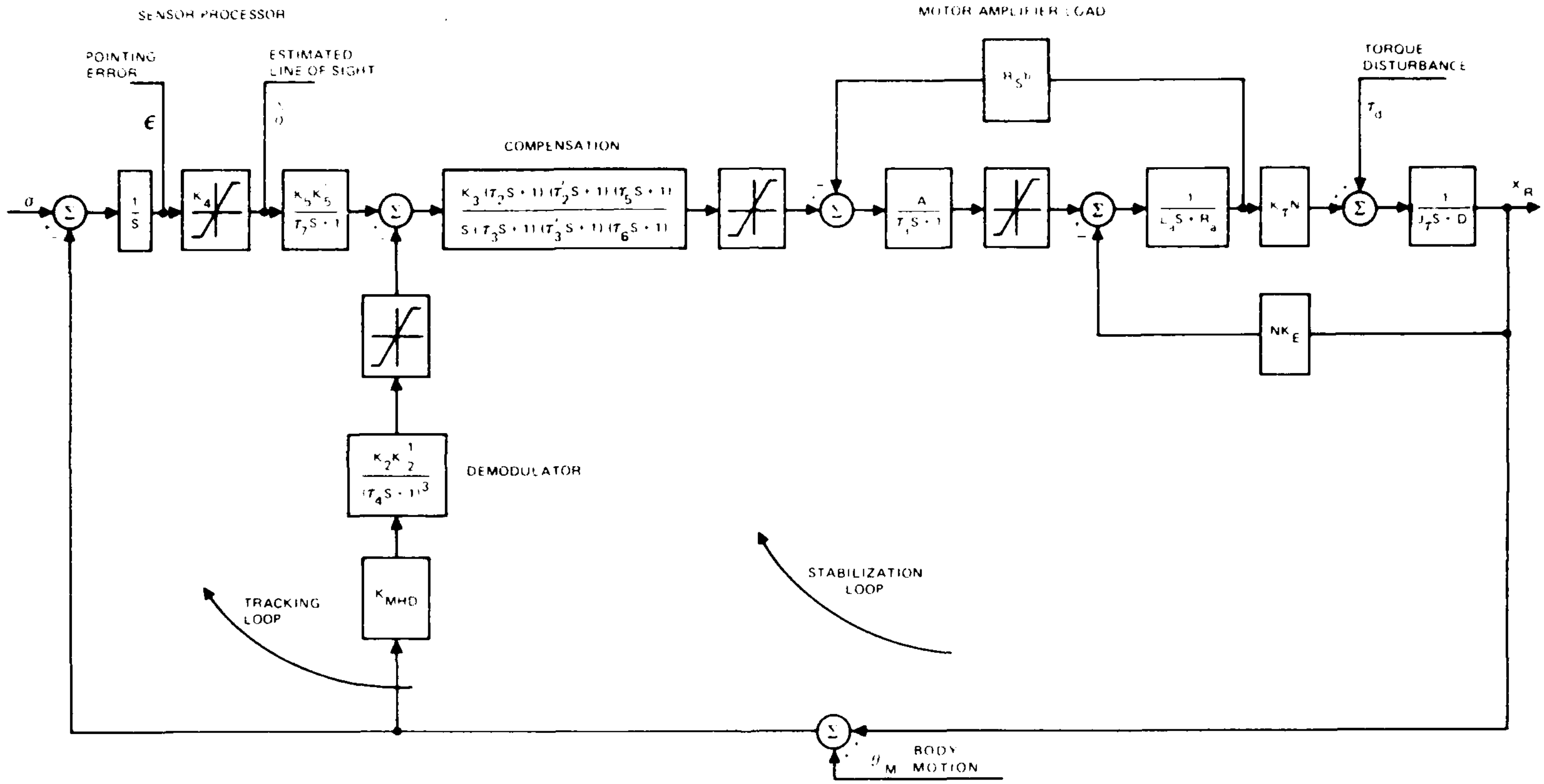


Figure 28. Track loop block diagram.

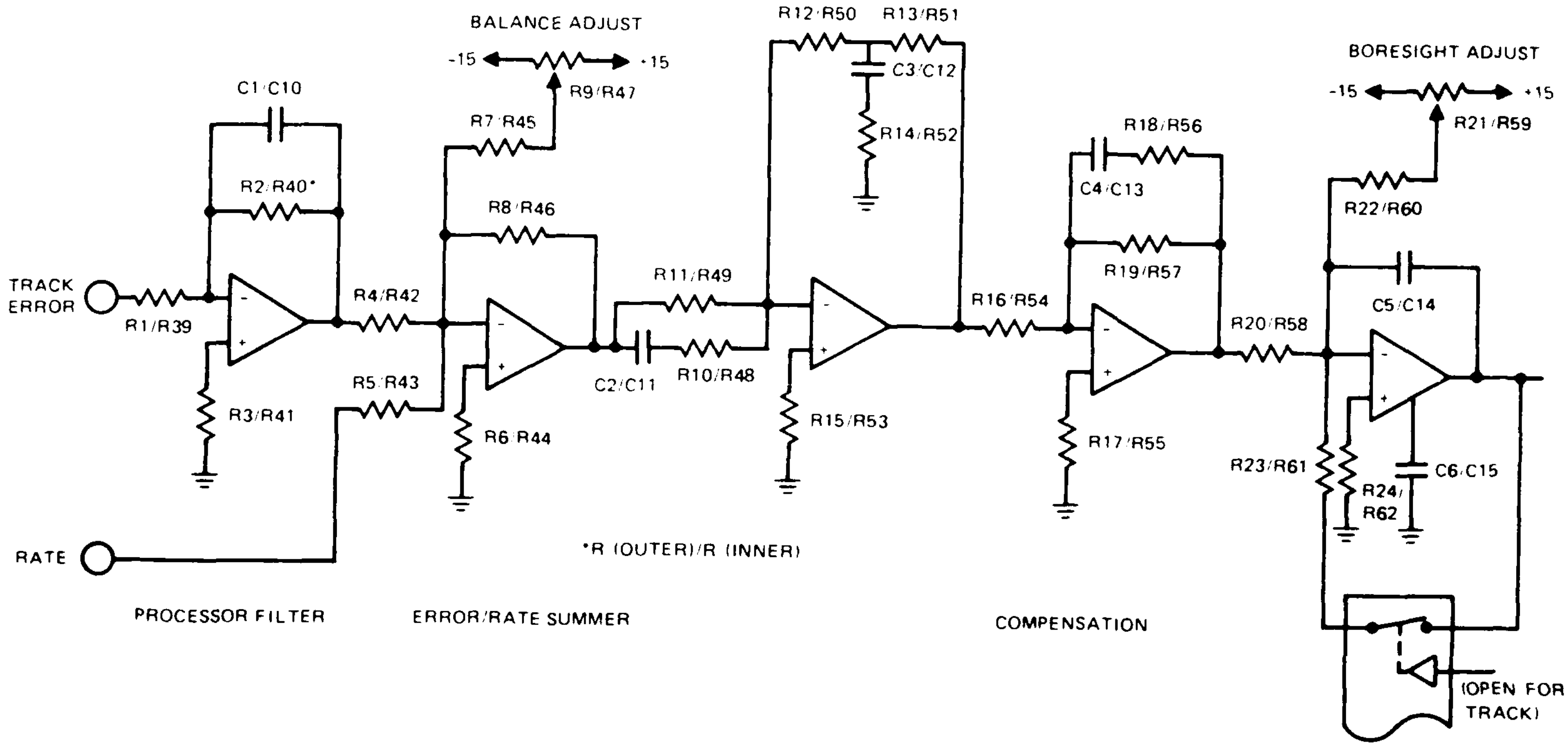


Figure 29. Track loop compensation.

Outer/Inner Components	Outer Gimbal	Inner Gimbal
R1/R39	3.3K	3.3K
R2/R40	24K	24K
R3/R41	3K	3K
R4/R42	3K	10K
R5/R43	1.1K	2.4K
R6/R44	2K	5.1K
R7/R45	2.2M	5.1M
R8/R46	10K	10K
R9/R47	50K pot	50K pot
R10/R48	12K	12K
R11/R49	110K	110K
R12/R50	56K	56K
R13/R51	56K	56K
R14/R52	3K	3K
R15/R53	56K	56K
R16/R54	91K	150K
R17/R55	68K	75K
R18/R56	30K	30K
R19/R57	270K	270K
R20/R58	100K	100K
R21/R59	50K pot	50K pot
R21/R59	50K pot	50K pot
R22/R60	10M	10M
R23/R61	470	470
R24/R62	51K	51K
R25/R63	10K	10K
C1/C10	1.0 μF	1.0 μF
C2/C11	0.082 μF	0.082 μF
C3/C13	3.3 μF	3.3 μF
C5/C14	1.0 μF	1.0 μF
C6/C15	100 pF	100 pF

Table 13. Track loop compensation component values.

a. PROCESSOR FILTER. The processor filter is used to smooth the signal output of the video processor. The transfer function to be obtained, per reference 1, is as follows:

$$\frac{K_4 K_5}{\tau_7 S + 1}.$$

The processor gain (K_4) in both outer and inner gimbal drive is 7.0, as predetermined by design of the processor network (if processor). This means that the processor filter gain (K_5) must be designed for 7.3 calculated as follows:

$$K_5 = \frac{R2}{R1} = 7.3 \text{ volts/volt (outer gimbal)}$$

$$K_4 = \frac{R40}{R39} = 7.3 \text{ volts/volt (inner gimbal).}$$

The processor filter time constant (τ_7) is calculated as follows:

$$\tau_7 = R2 \times C1 = 0.024 \text{ second (outer gimbal)}$$

$$\tau_7 = R40 \times C10 = 0.024 \text{ second (inner gimbal).}$$

b. ERROR/RATE SUMMER. The error/rate summer sums the track error and rate (stabilization) signals and balances them. To accomplish this, it was necessary to calculate the following gains.

Outer Gimbal.

$$K_2^1 = \frac{R8}{R5} = 9.09 \text{ volts/volt}$$

$$K_2^1 = \frac{R8}{R4} = 3.33 \text{ volts/volt.}$$

Inner Gimbal.

$$K_2^1 = \frac{R46}{R43} = 4.17 \text{ volts/volt}$$

$$K_2^1 = \frac{R46}{R42} = 1.00 \text{ volt/volt.}$$

K_2^1 is the rate gain (demodulator gain) and K_5^1 is the error gain (processor gain).

c. COMPENSATION FILTER. A lead-lag compensation network was necessary to provide the required stability. The transfer function for the track-loop compensation filter, per reference 1, is as follows:

$$\frac{K_3(\tau_2 S+1)(\tau_2^1 S+1)(\tau_5 S+1)}{S(\tau_3 S+1)(\tau_3^1 S+1)(\tau_6 S+1)} .$$

The calculations of the compensation filter gain (K_3) and the time constants (τ_2, τ_2^1, τ_3, τ_3^1, τ_5, and τ_6) for both the inner and outer gimbals are shown in table 14. The last stage of the compensation filter is an integration and translates to gain included in K_3 [integrator gain = 1/R20C5 (outer gimbal) and 1/R58C14 (inner gimbal)].

2. Magnetohydrodynamic Rate Sensor (MHD)

A Minneapolis-Honeywell MHD two-axis rate sensor (GG2500) is used as the stable platform inertial reference. This single instrument closes both inner and outer gimbal stabilization loops. Figure 30 shows the MHD. This small, compact inertial rate measuring device makes it practical to fabricate small radar seekers.

The MHD rate sensor is an angular accelerometer with a liquid metal proof mass. Motion of the proof mass relative to the case is "magnetohydrodynamically" sensed to measure angular acceleration. The accelerometer case is rotated about an axis normal to the sense axis by a small hysteresis-type ac motor; this results in an ac output of the accelerometer where magnitude is proportional to the polar angular rate, and whose phase is a measure of the direction of the polar vector in the rotation plane. A reference generator is provided on the rotation axis whose output is a two-phase ac voltage synchronous with the accelerometer ac output. The two-phase reference generator outputs are used as switching reference voltages for two-phase detectors which convert the ac polar rate measurement into dc voltages which are proportional to the inner and outer gimbal components of the polar rate. The accelerometer output is a sinewave-modulated ac carrier frequency of 200 Hertz where the modulation contains the polar rate information. The gain of the MHD (K_{MHD}) is 0.8595 volt rms/radian/second.

3. Demodulator

Dual in-line integrated circuits and discrete components were used for the demodulator when it was first fabricated. Subsequently, Honeywell developed a hybrid package (1030AD06) which is now incorporated into the electronics. The demodulator has quadrature-switched phase detectors which extract quadrature components of the modulation to derive dc signals proportional to the inner and outer gimbal rates. The MHD reference generator provides the switching voltages for the two-phase detectors. The dc conversion requires a low-pass filter following the phase detectors to attenuate the carrier frequency ripple. This filter determines the maximum bandwidth achievable in any stabilization loop using this rate sensor. In this application, the filters limit the bandwidth to 20 Hertz. The transfer function and associated gains, time constants, and damping factors are shown in table 15. For purposes of displaying the derivation of these values, the demodulator is divided into three phases: 200-Hertz bandpass filter, phase detectors/filter, and third-order filter.

Outer Gimbal.

$$K_3 = \frac{(R12 + R13)\,R19}{R_{11}R_{16}R_{20}C_5} = 30.2 \text{ volts/volt}$$

$$\tau_2 = (R_{11} + R_{10})\,C_2 = 0.0100 \text{ second}$$

$$\tau_2^1 = \frac{R_{12} + R_{13}}{4} + R_{14}C_3 = 0.0102 \text{ second}$$

$$\tau_3 = R_{10}C_2 = 0.000984 \text{ second}$$

$$\tau_3^1 = R_{14}C_3 = 0.000990 \text{ second}$$

$$\tau_5 = R_{18}C_4 = 0.0990 \text{ second}$$

$$\tau_6 = (R_{18} + R_{19})\,C_4 = 0.990 \text{ second}$$

Inner Gimbal

$$K_3 = \frac{(R50 + R51)\,R57}{R49R54R58C14} = 18.3 \text{ volts/volt}$$

$$\tau_2 = (R49 + R48)\,C11 = 0.0100 \text{ second}$$

$$\tau_2^1 = \frac{R50 + R51}{4} + R52C12 = 0.0102 \text{ second}$$

$$\tau_3 = R48C11 = 0.000984 \text{ second}$$

$$\tau_3^1 = R52C12 = 0.000990 \text{ second}$$

$$\tau_5 = R56C13 = 0.0990 \text{ second}$$

$$\tau_6 = (R56 + R57)\,C13 = 0.990 \text{ second}$$

$$\tau_6 = (R56 + R57)\,C13 = 0.990 \text{ second}$$

Table 14. Track compensation filter calculations.

Figure 30. Magnetohydrodynamic rate sensor (MHD).

$$\frac{K_{MND}K_{D1}K_{D2}K_{D3}S}{(\tau_{4C}S+1)(\tau_{4A}^2S^2+2\delta_A\tau_{4A}S+1)(\tau_{4D}S+1)(\tau_{4B}^2S^2+2\delta_B\tau_{4B}S+1)}$$

where

K_{MND} = 0.8595 V_{rms}/rad/s (MHD gain)

K_{D1} = 1.11 × 10^{-3} V_{rms}/V_{rms} (200-Hz bandpass filter gain)

K_{D2} = 4.56 V_{avg}/V_{rms} (rectifier gain)

K_{D3} = 1.00 Vdc/V_{avg} (third-order filter gain)

τ_{4C} = 0.00308 second (third-order filter time constant)

τ_{4B} = 0.00105 second (third-order filter time constant)

τ_{4D} = 0.000214 second (full-wave rectifier time constant)

τ_{4A} = 0.000760 second (200-Hz bandpass filter time constant)

δ_B = 0.053 (third-order filter damping factor)

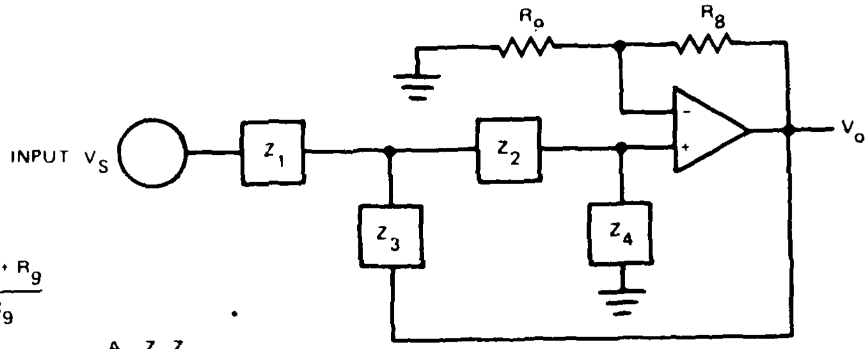
δ_A = 1.00 (200-Hz bandpass filter damping factor).

Table 15. Demodulator transfer function and values.

a. 200-HERTZ BANDPASS FILTER. The 200-Hz bandpass filter is used to pass the 200-Hz signal received from the MHD and attenuate all other frequencies. Figure 31 is a simplified schematic taken from reference 2, which indicates how to derive its transfer function. The component values are shown in table 16; the transfer function and calculations of the gain (K_{D1}), the time constant (τ_{4A}), and the damping factor (δ_A) in table 17.

b. PHASE DETECTORS/FILTER. The phase detectors produce the quadruplexing action necessary to decipher the incoming 200-Hz signal. A 400-Hz reference is generated by the MHD and is transformed to a 400-Hz square wave. This square wave is used to switch the phase detectors that separate the inner gimbal motion from the outer gimbal motion that results from the incoming 200-Hz signal. The two-phase detectors are tied in tandem. The filter following the phase detectors attenuates the switching ripple. A simplified schematic of the phase detectors/filter is shown in figure 32. The component values are shown in table 18. The transfer function and calculations of the gain (K_{D2}) and the time constant (τ_{4C}) are shown in table 19.

[2]Stout, D. S., and M. Kaufman. Handbook of Operational Amplifier Circuit Design. McGraw-Hill, Inc. 1976, p 10-8



$$A_{V_o} = \frac{R_8 + R_9}{R_9}$$

$$\frac{V_o}{V_S} = \frac{A_{V_o} Z_3 Z_4}{Z_3(Z_1 + Z_2 + Z_4) + Z_1 Z_2 + Z_1 Z_4 (1 - A_{V_o})}$$

$$Z_1 = R_5$$

$$Z_2 = \frac{1}{C_7 S}$$

$$Z_3 = R_6$$

$$Z_4 = \frac{R_7}{R_7 C_8 S + 1}$$

Figure 31. 200-Hz bandpass filter schematic.

R5	162K
R6	51.1K
R7	316K
R8	21.5K
R9	46.4K
C7	0.01 μF
C8	4700 pF
C9	100 pF

Table 16. 200-Hz bandpass filter component values.

$$\frac{K_{D1}S}{J^2A + SB + 1}$$

$$K_{D1} = 1.11 \times 10^{-3}\ V_{rms}/V_{rms} = \frac{A_{v_0}R_6R_7C_7}{R_5 + R_6}$$

$$A = 5.77 \times 10^{-7} = \frac{R_5R_6R_3C_7C_8}{R_5 + R_6}$$

$$B = 1.52 \times 10^{-3} = R_5R_6R_7C_8 + R_6R_7C_8 + R_6R_7C_7 + (1 - A_{v_0})R_5R_7C_7$$

Roots

$$(\tau_{4A}S)^2 + 2\delta_A\tau_{4A}S + 1 \qquad \tau_{4A} = 0.00076 \text{ second}$$

$$\delta_A = 1.0$$

Gain at 200 Hz = 0.73.

Table 17. 200-Hz bandpass filter calculations.

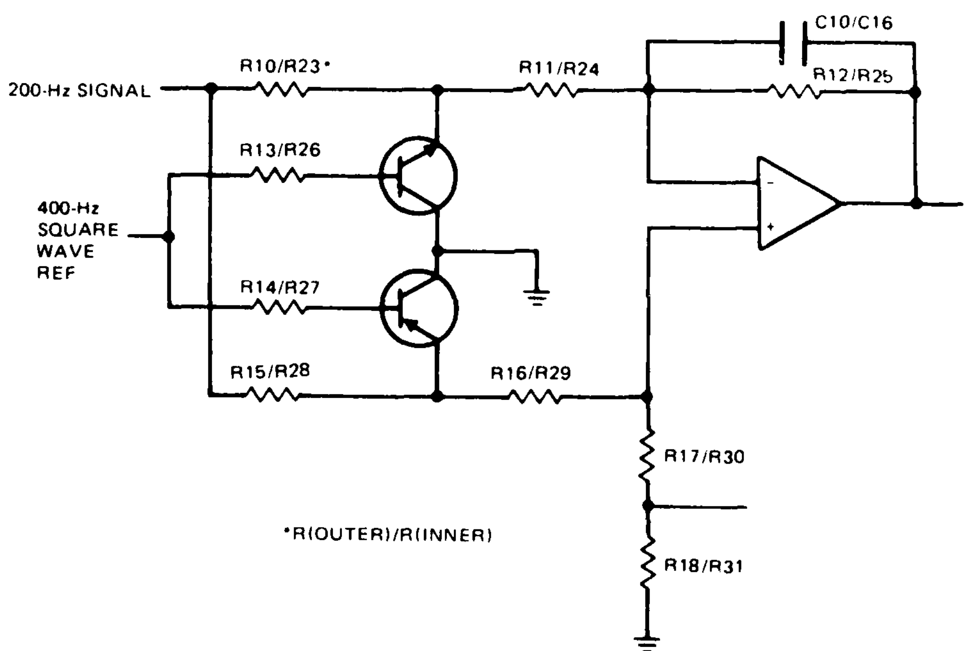


Figure 32. Phase detectors/filter schematic.

Outer/Inner Component	Outer Gimbal	Inner Gimbal
R10/R23	6.34K	6.34K
R11/R24	6.34K	6.34K
R12/R25	65K (select)	65K (select)
R13/R26	10K	10K
R14/R27	10K	10K
R15/R28	39.2K (select)	39.2K (select)
R16/R29	6.34K	6.34K
R17/R30	37.4K	37.4K
R18/R31	56.2K	56.2K
C10/C16	3300 pF	3300 pF

Table 18. Phase detectors/filter component values.

Outer Gimbal

$$K^{1}_{D2-} = \frac{R12}{R10 + R11} = 5.07\ V_{rms}/V_{rms} \text{ (negative half-cycle gain)}$$

$$K^{1}_{D2+} = \frac{(R17 + R18)(R11 + R12)}{R11\,(R15 + R16 + R17 + R18)} = 5.07\ V_{rms}/V_{rms} \text{ (positive half-cycle gain)}$$

$$K_{D2} = K^{1}_{D2+}\ \frac{0.636}{0.707} = 4.56\ V_{avg}/V_{rms}$$

$$\tau_{4D} = R12C10 = 0.000214 \text{ second.}$$

Inner Gimbal.

$$K^{1}_{D2} = \frac{R25}{R23 + R24} = 5.07\ V_{rms}/V_{rms} \text{ (negative half-cycle gain)}$$

$$K^{1}_{D2+} = \frac{(R30 + R31)(R24 + R25)}{R24\,(R28 + R29 + R30 + R31)} = 5.07\ V_{rms}/V_{rms} \text{ (positive half-cycle gain)}$$

$$K_{D2} = D^{1}_{D2+}\ \frac{0.636}{0.707} = 4.56\ V_{avg}/V_{rms}$$

$$\tau_{4D} = R25C16 = 0.000214 \text{ second.}$$

Table 19. Phase detectors/filter calculations.

c. THIRD-ORDER FILTER. The third-order filter is a low-pass filter that follows the phase detector/filter used to attenuate the carrier frequency ripple. This filter determines the maximum bandwidth. Figure 33 is a simplified schematic of the third-order filter. The component values are shown in table 20 and the transfer function and calculations (τ_{4B} and τ_{4C}) and damping factor (δ_B) in table 21. The equation for the transfer function was obtained from reference 3.

4. APPROXIMATED MHD/DEMODULATOR TRANSFER FUNCTION

For ease of implementing on the computer, reference 1 used the following transfer function to approximate the MHD/demodulator circuits:

$$\frac{K_{MHD}K_2}{(\tau_4 S+1)^3}$$

The same transfer function and the following data apply for both inner and outer gimbal electronics. The MHD gain (K_{MHD}) is 0.8595 volt rms/radian/second. The demodulator gain (K_2) is 3.33 volts dc/volts rms. K_2 is equivalent to $K_{D1}K_{P2}K_{D3}$ of the calculated transfer function. A time constant of 0.0015 second (τ_4) was calculated as an approximation of the MHD demodulator circuits.

IV. MECHANICAL DRAWINGS

It is recognized that the drawings in this section are not comprehensive; however, it is believed that they are complete enough to aid in analysis of the servo platform system.

Figure 34 is an outline drawing of the control panel. The control panel is made of sheetmetal.

The last figures in this document are the mechanical drawings of the platform and the associated mountings to the platform. Figure 35 shows the mounting of the bail ring to the base. Figure 36 shows the base mount dimensions. Figure 37 shows the bail ring and bearings. Figure 38 shows the roller and spacer used to hold the bail ring. Figure 39 shows the inner motor mount. Figure 40 shows the inner potentiometer mount. Figure 41 shows the outer potentiometer mount.

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[3] Millman, Jacob, and C. C. Halkias, Integrated Electronics: Analog and Digital Circuits and Systems, McGraw-Hill, Inc., 1972, p. 552.

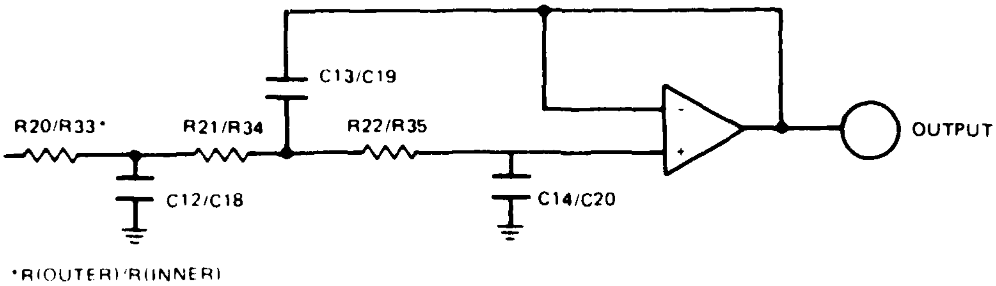


Figure 33. Third-order filter schematic.

Outer/Inner Components	Outer Gimbal	Inner Gimbal
R20/R33	100K	100K
R21/R34	100K	100K
R22/R35	100K	100K
C12/C18	0.022 μF	0.022 μF
C13/C19	0.047 μF	0.047 μF
C14/C20	3300 pF	3300 pF

Table 20. Third-order filter component values.

$$\frac{K_{D3}}{S^3A + S^2B + SC + 1}$$

	Inner Gimbal	Outer Gimbal
K_{D3}	$= C_{18}C_{19}C_{20}R_{33}R_{34}R_{35}$	$C_{12}C_{13}C_{14}R_{20}R_{21}R_{22}$
B	$= C_{18}C_{19}C_{20}(R_{33} + R_{34})$ $+ C_{18}C_{20}R_{33}(R_{34} + R_{35})$	$C_{12}C_{13}C_{14}(R_{20} + R_{21})$ $+ C_{12}C_{14}R_{20}(R_{21} + R_{22})$
C	$= C_{18}R_{33} + C_{20}(R_{33} + R_{34} + R_{35})$	$C_{12}R_{20} + C_{14}(R_{20} + R_{21} + R_{22})$
Solution		
A	$= 3.4122 \times 10^{-9}$	3.4122×10^{-9}
B	$= 1.452 \times 10^{-6}$	1.452×10^{-6}
C	$= 3.19 \times 10^{-3}$	3.19×10^{-3}

Roots

$(\tau_{4C}S + 1)(\tau_{4B}^2S^2 + 2\delta_B\tau_{4B}S + 1)$

τ_{4C} = 0.00308 second

τ_{4B} = 0.00105 second

δ_B = 0.053 second.

Table 21. Third-order filter calculations.

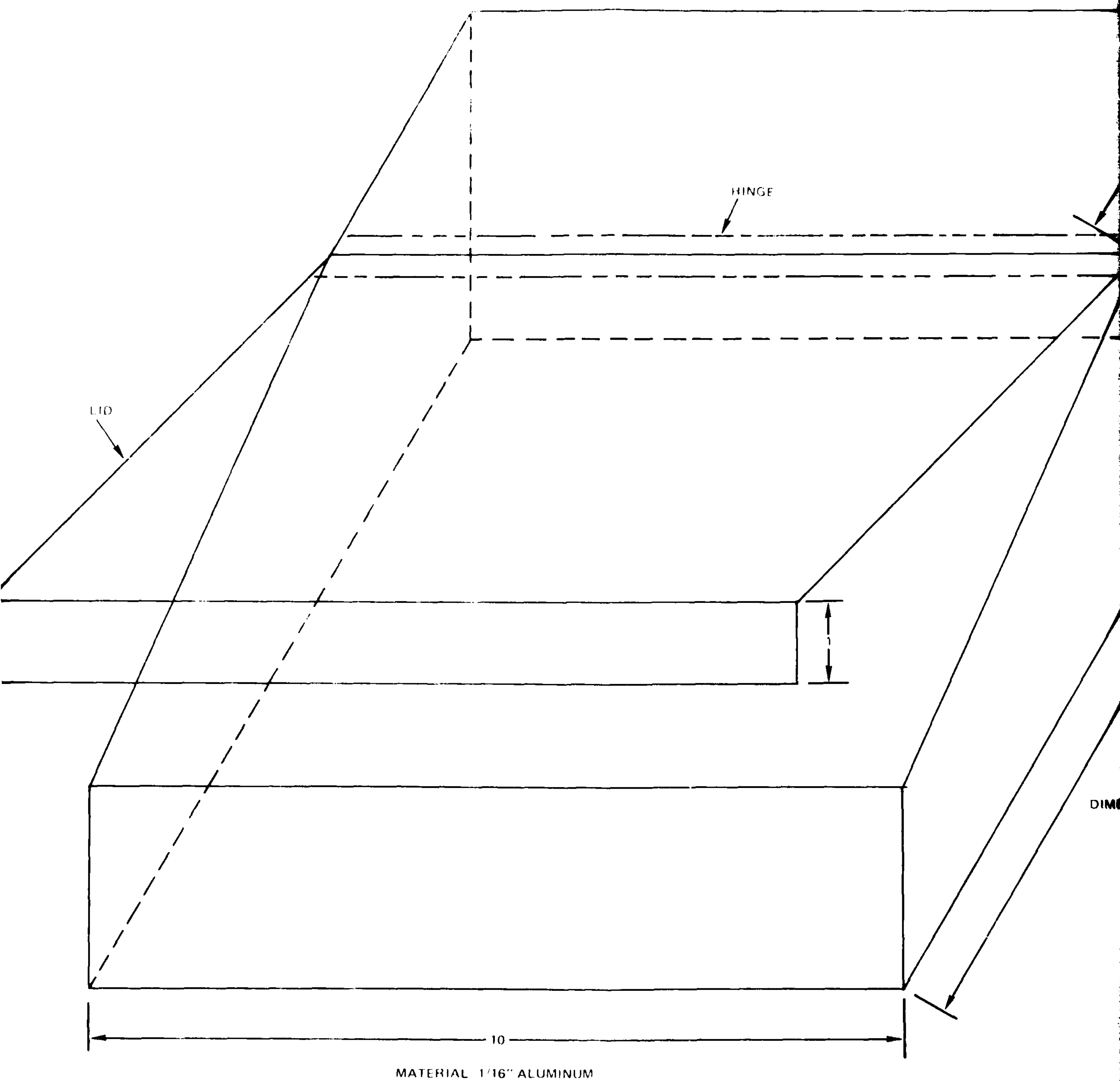
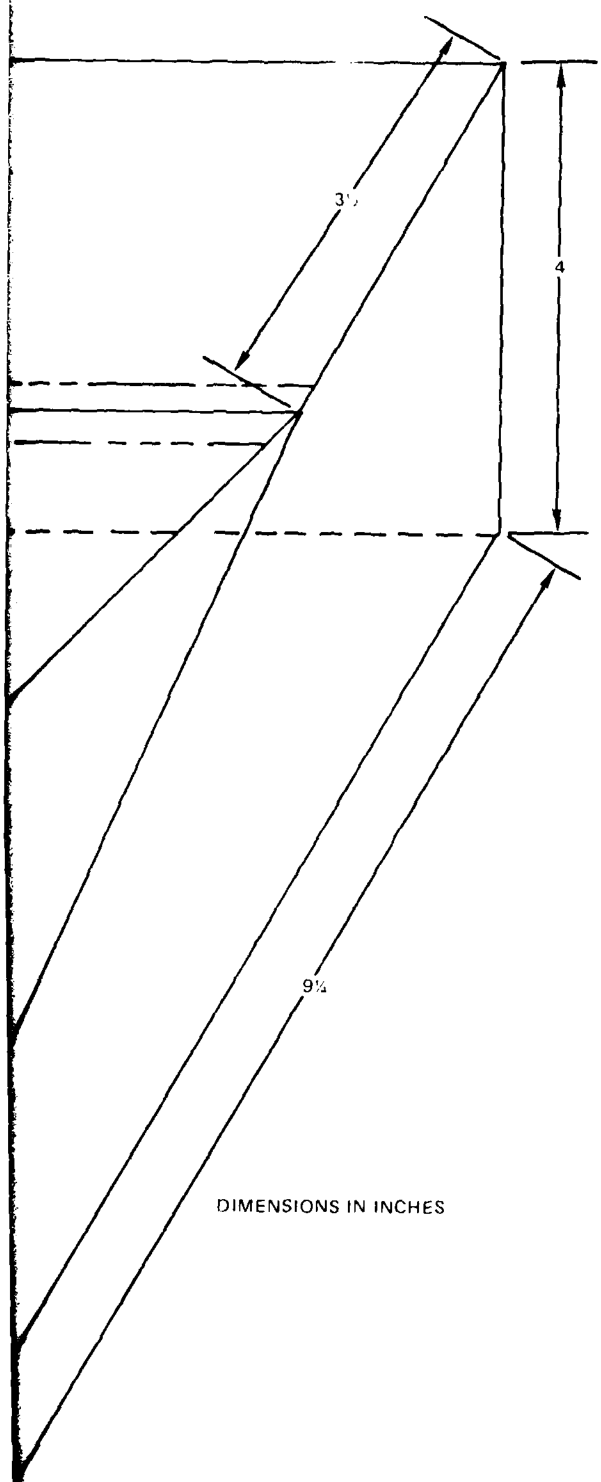
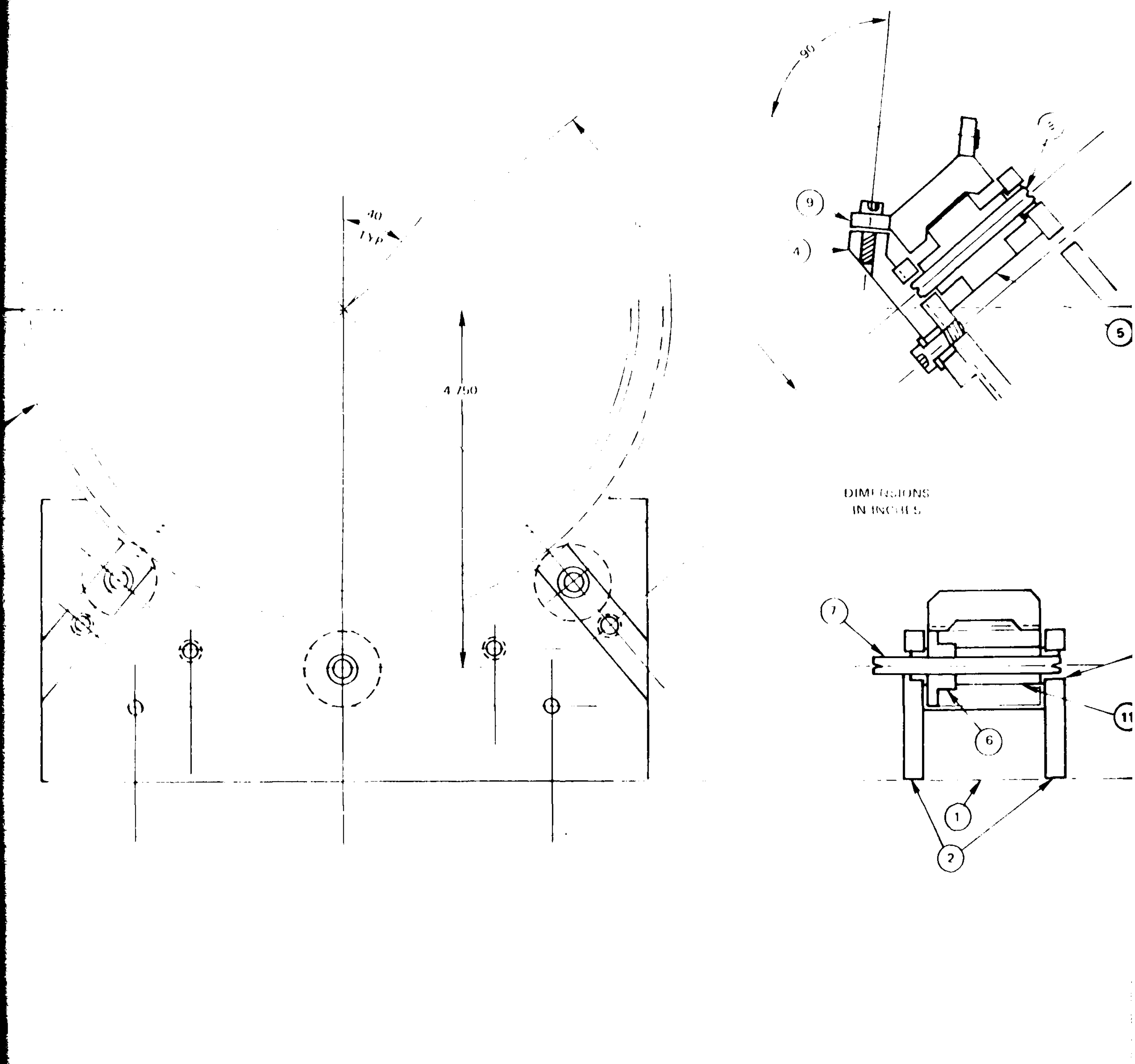


Figure 34. Control panel outl



34. Control panel outline and hinged lid (perspective).



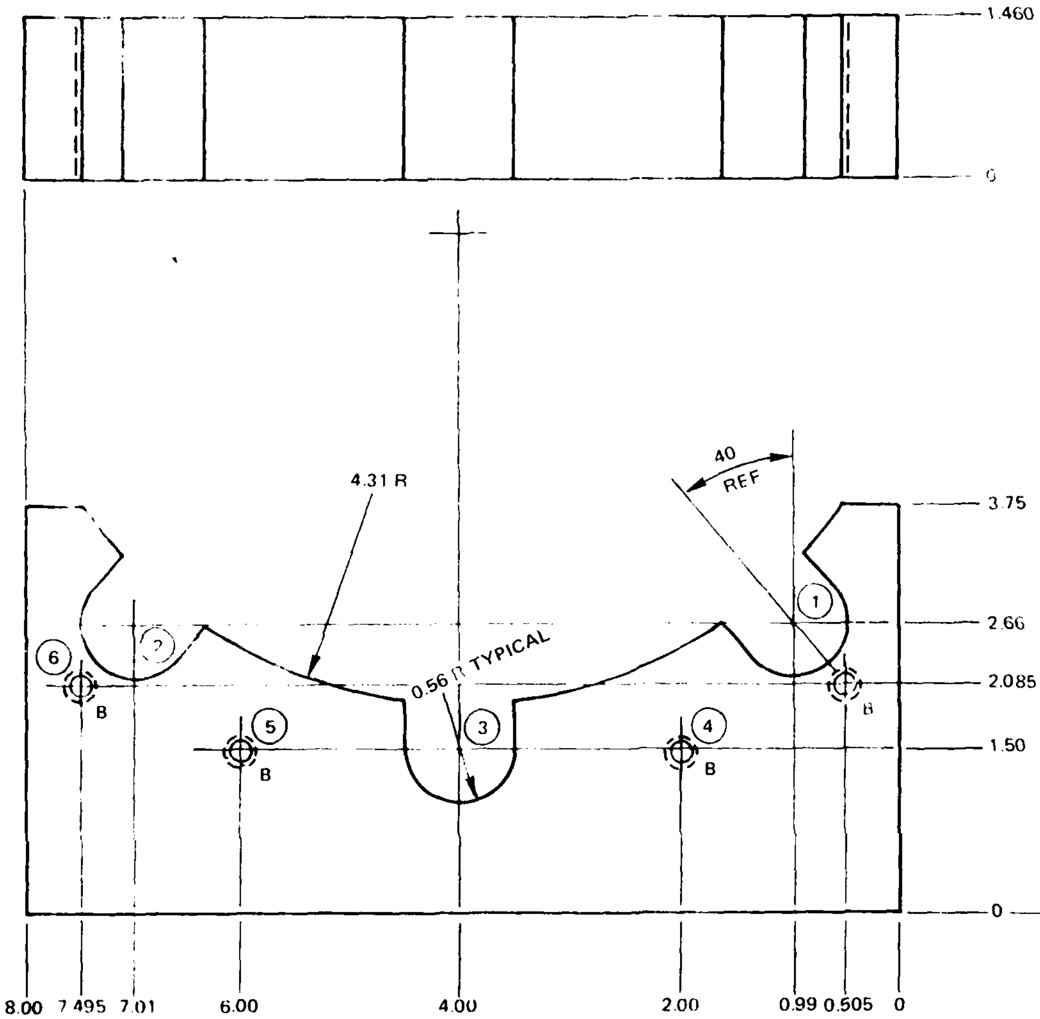
90
.40
TYP
4.750
9
4
5
DIMENSIONS
IN INCHES
7
11
6
1
2

12	MOTOR MOUNT	ALUM	1
	MISCELLANEOUS DOWEL PINS, SCREWS, WASHERS	- -	AS NECESSARY
11	SPACER	- -	1
10	OILITE BUSHING	- -	6
9	BALL BEARING	- -	4
8	SHAFT		2
7	SHAFT		1
6	PINION		1
5	ROLLER	CRES	2
4	BEARING MOUNT	CRS	4
3	BAIL RING	ALUM	1
2	SIDE PLATE	ALUM	2
1	BODY	ALUM	1
DET	DESCRIPTION	MAT'L	QTY

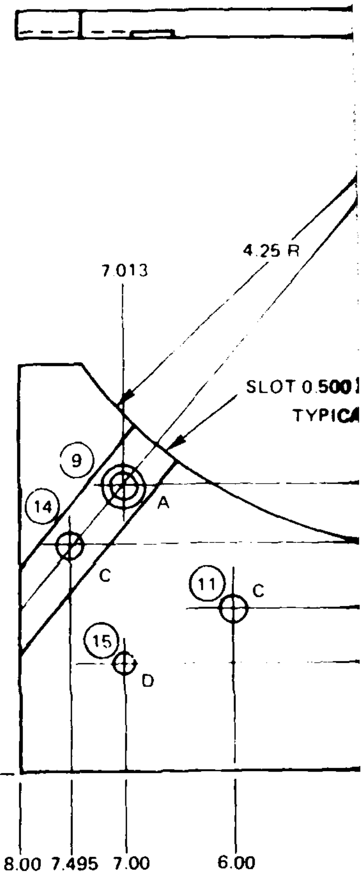
Figure 35. Platform drawing sheet 1: bail ring mounting.

	HOLE SPECS
A	0.375 ⌀ THROUGH
B	1/4-20 THREAD THROUGH
C	0.250 ⌀ THROUGH
D	0.187 ⌀ THROUGH DOWEL @ ASSEMBLY

ALL DIMENSIONS IN INCHES



DETAIL 1 BODY



DE

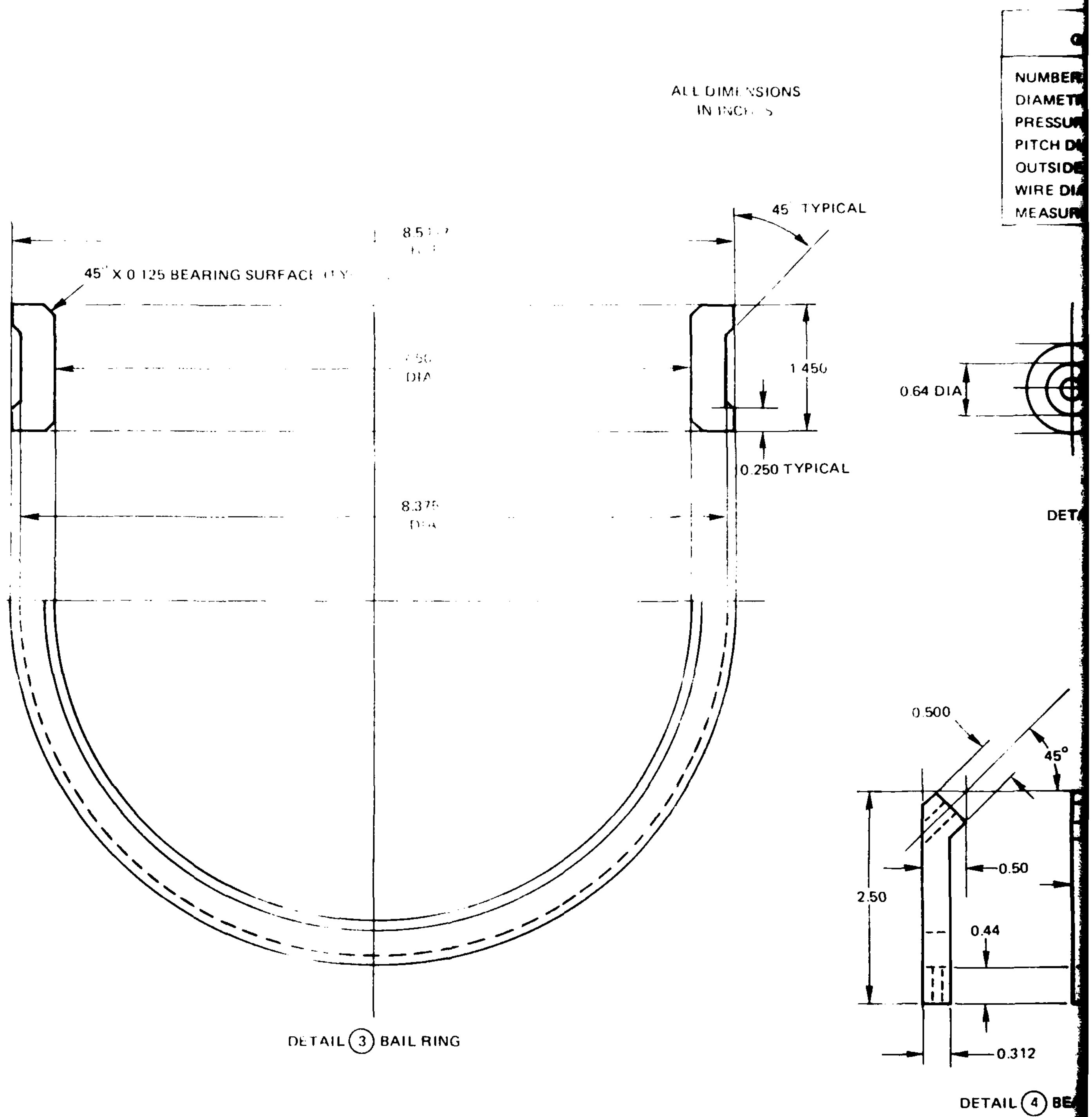
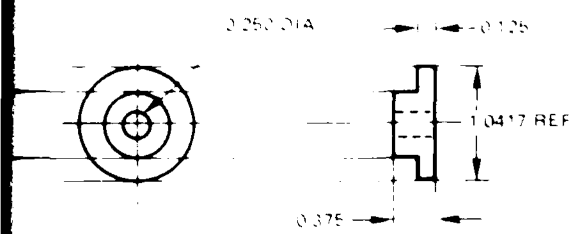
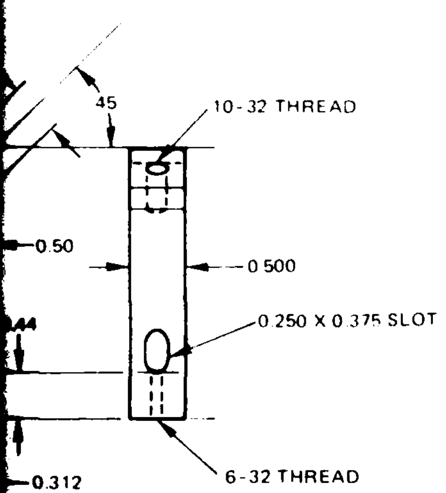

ALL DIMENSIONS IN INCHES
45° TYPICAL
45° X 0.125 BEARING SURFACE
1.450
0.250 TYPICAL
8.375 DIA
DETAIL 3 BAIL RING
NUMBER
DIAMET
PRESSU
PITCH DI
OUTSIDE
WIRE DIA
MEASUR
0.64 DIA
DETA
0.500
45°
0.50
2.50
0.44
0.312
DETAIL 4 BE

Figure 37.

GEAR SPECS	[illegible] BAIL RING	DET 6 PINION
NUMBER OF TEETH	[illegible]	48
DIAMETRAL PITCH	[illegible]	48
PRESSURE ANGLE	[illegible]	20
PITCH DIA	[illegible]	1.000
OUTSIDE DIA	[illegible]	1.0417
WIRE DIA	[illegible]	0.036
MEASUREMENT OVER WIRES	[illegible]	1.0505



DETAIL (6) PINION



TAIL (4) BEARING MOUNT

Figure 37. Platform drawing sheet 3 – bail ring and bearings.

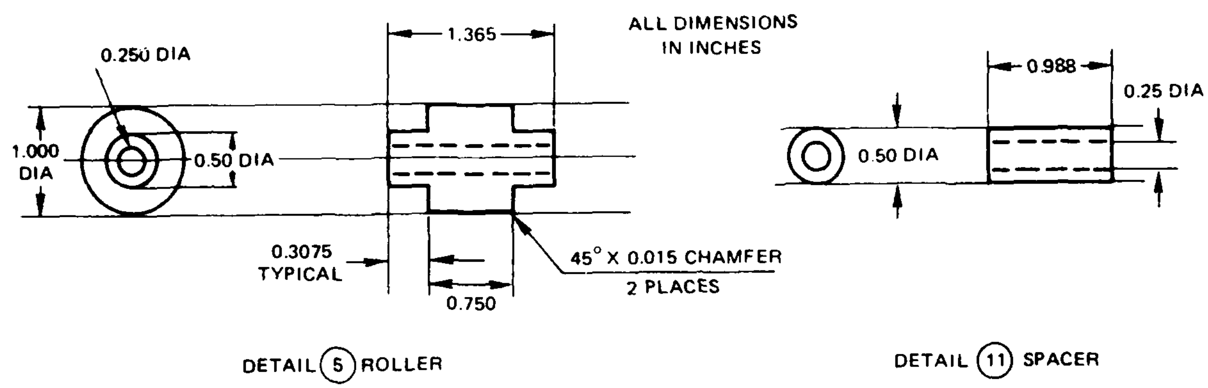


Figure 38. Platform drawing sheet 4: roller and spacer.

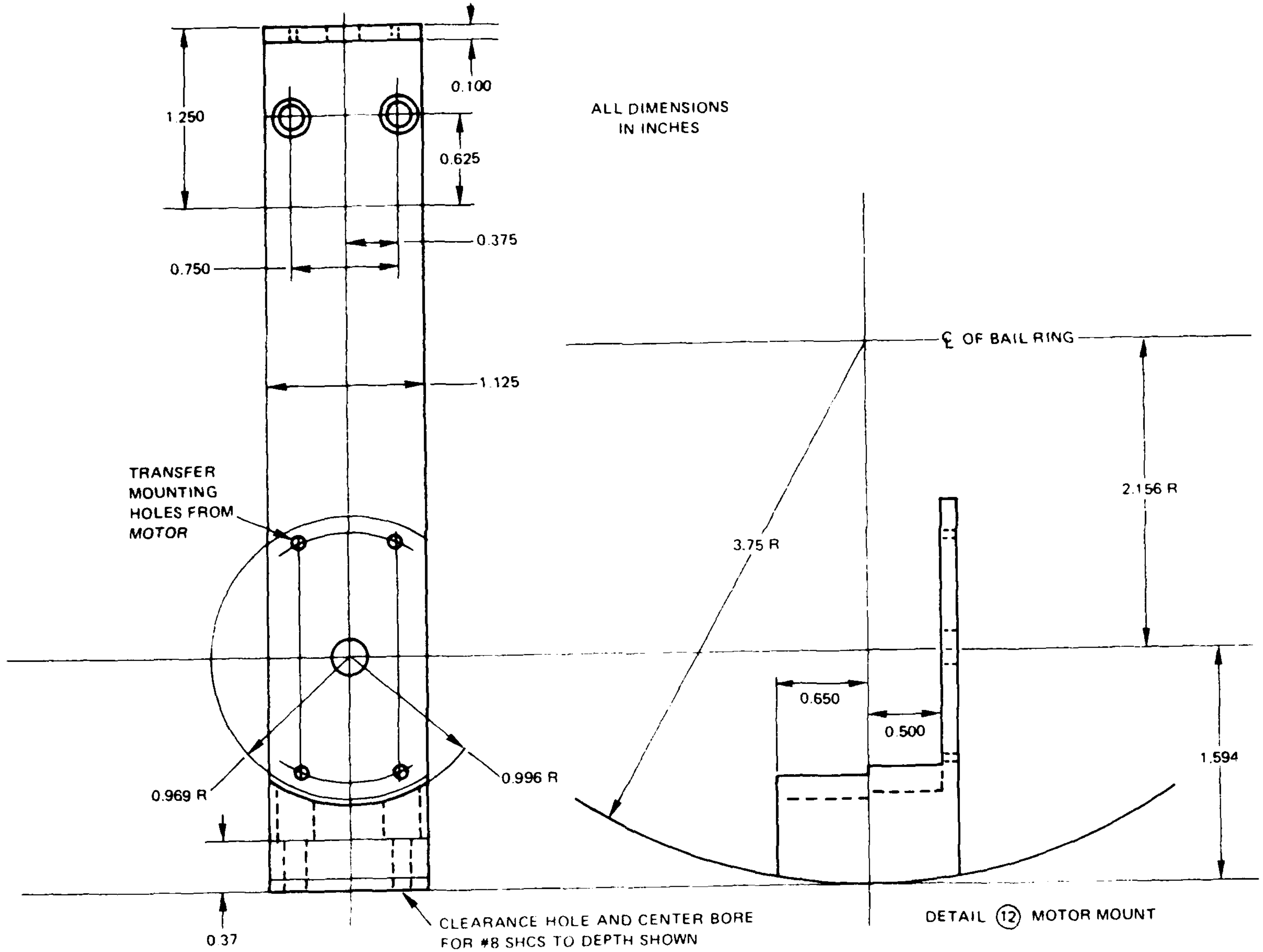


Figure 39. Platform drawing sheet 5: inner motor mount.

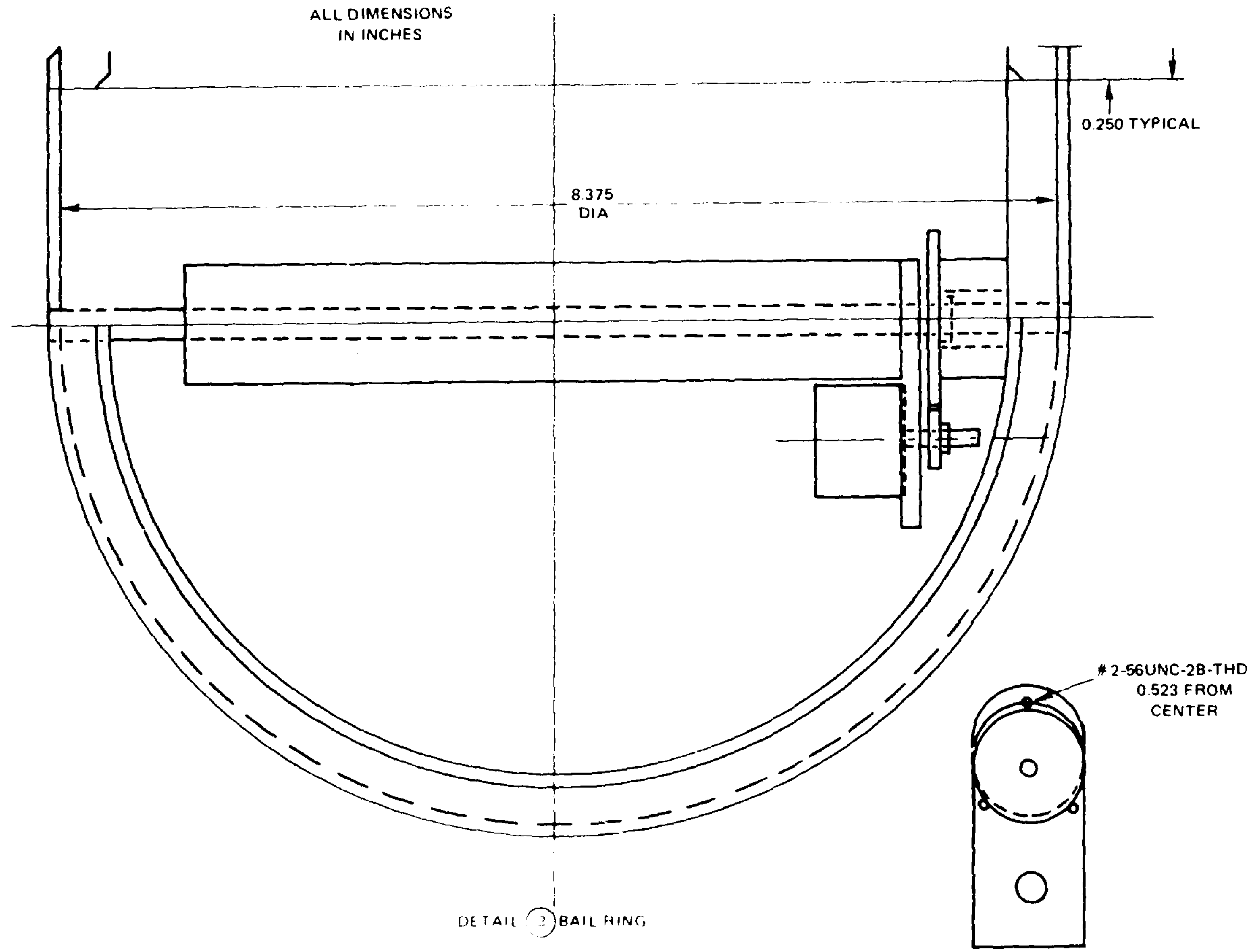


Figure 40. Platform drawing sheet 6 – inner potentiometer mount.

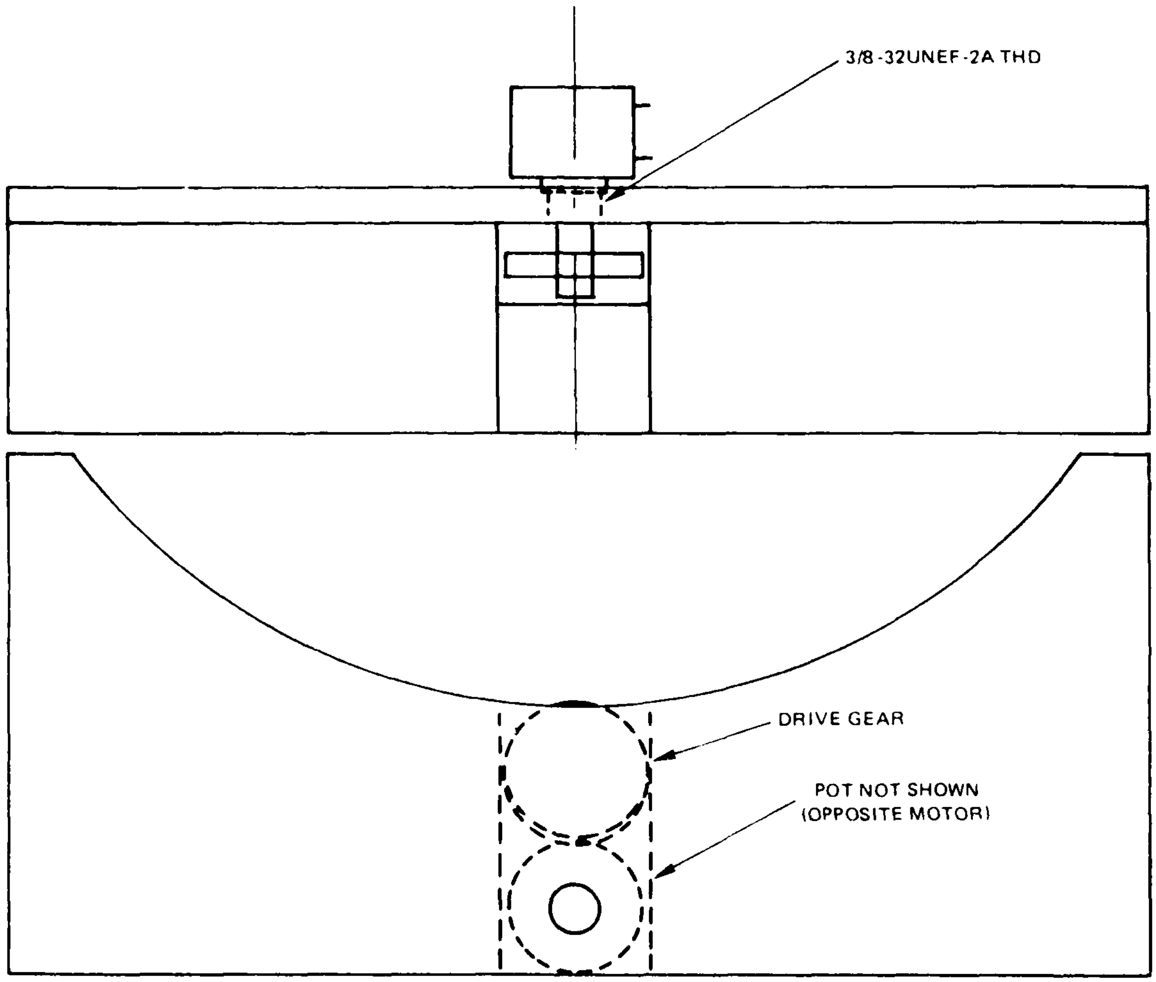


Figure 41. Platform drawing sheet 7: outer potentiometer mount.

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